54TH CONGRESS, 2d Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 342.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 2

IRRIGATION NEAR PHŒNIX, ARIZONA.—DAVIS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION NEAR PHŒNIX, ARIZONA

BY

ARTHUR POWELL DAVIS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, January 25, 1897.

SIR: I have the honor to transmit herewith a paper entitled "Irrigation near Phœnix, Arizona," by Arthur P. Davis, hydrographer, and to recommend that it be published in the series of papers "in relation to the gauging of streams and to the methods of utilizing the water resources," the printing of which was authorized in the act making appropriations for sundry civil expenses of the Government for the fiscal year ending June 30, 1897, approved June 11, 1896.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PREFACE.

The storage of flood waters on a large scale is fast coming to be a matter of prime importance in connection with the development of the arid portions of the United States. The irrigation projects which involve comparatively small expenditure, or which can readily be handled by associated effort, have already been entered upon, but there still remain many localities where, as time goes on, the necessity for water conservation becomes more and more pressing. This is especially the case in southern Arizona, in the Salt and Gila valleys. Here, under the genial semitropic conditions, large returns are obtained from the fertile soil, some of the most valuable fruits are raised, and crop follows crop in rapid succession, farming operations being continued throughout the year.

The success of agriculture has been such that a considerable number of large irrigating canals have been built and lateral ditches extended until the available supply during low water has been practically exhausted. The streams of this country are, however, extremely irregular in character, fluctuating at times with great rapidity, floods coming down without warning, and disappearing in the course of a few hours. At certain seasons of the year high waters prevail and run to waste to the Gulf, or disappear by evaporation and percolation into the sandy desert. It is obvious that by providing suitable storage works the area of land to be irrigated can be greatly increased, the limiting conditions being practically the cost of storing water relative to the value of the crops produced.

The conditions briefly described above are not peculiar to the vicinity of Phœnix, or even to the Territory of Arizona; they prevail in greater or less degree throughout the more arid parts of the United States, for in nearly every portion of this country irrigation has been demonstrated to be successful and largely profitable. Systems of water supply have been built, the more easily available waters utilized, and the extension of irrigable lands now rests mainly upon the conservation of waste waters. It is for this reason that a discussion of the conditions near Phœnix, Arizona, has an interest not only to the citizens of that locality, but in general is of value to residents in other portions of the West. In certain respects the needs for water are more pressing in southern Arizona than elsewhere, and thus the probabilities of early solution of some of the problems of water storage are here more likely to be settled in the near future. For this reason the following paper by Mr. Davis will be of benefit to a larger circle of readers than those to whom, from the title, it may appear to be addressed.

In order to make clear all of the surroundings, Mr. Davis gives a general description of the topographic and climatic conditions of the Salt and Gila valleys, and of the irrigation works already constructed. He also mentions the legal complications which have arisen, and outlines some of the projects now being constructed. He points out the great natural advantages of this country, and shows as far as data can be procured the facts relating to water supply, evaporation, silting of reservoirs, and other factors which make or mar projects of water conservation.

At first sight the storage of water appears to be a very simple matter. In popular discussions it is common to assume that the only steps necessary are to place rock or timber obstructions in some of the many canyons or narrow places along the course of the river in order to hold back the water of floods, and later allow it to flow down the stream as necessity requires. On carefully examining any proposition of this kind, many obstacles are found to arise, some of these natural—such as the difficulty of finding a proper location, the expense of laying foundation, and the liability of the reservoir to fill by silt—and others artificial or legal, such as interference with vested rights, and difficulties of securing title to the stored water after it has left the reservoir and is on the way to the land to be covered.

A traveler going over the Territory sees here and there almost numberless places where it appears probable that a storage dam might be built holding behind it considerable water, but when a careful survey has been made it is usually found that the slope of the stream is so great that if a dam were built the amount of water held behind it would be relatively too small to repay the cost of construction. Should it be found that there is ample space behind the selected dam site, further investigation may reveal the fact that solid rock can not be found at moderate depth beneath the surface. In other words, the stream has washed into the gorge such a mass of loose material as to fill it to a depth of 20, 40, or even 60 feet or more. To remove this, place the foundation on bed rock, and then rear a structure to the proper height, will necessitate the expenditure of such large sums as to render the enterprise impracticable. This is a very common condition within the arid region, where the drainage lines, dry for a great part of the year, are filled, perhaps for a few days or even a few hours only, with a great torrent resulting from excessive local rainfall. The water discharged down the steep slopes dislodges not only the accumulated sand and dust which has been blown about by the desert winds, but rolls along gravel and bowlders into the channels. Even in the narrow gorges through which these sometimes pour the velocity of the water is not sufficient, except perhaps in extraordinary floods, to tear out the loose material and reach bed rock. Thus the gravel and bowlders accumulate during the lesser floods all along the course of the stream, covering the dam sites, and form long lines of barren wash.

Not only does the loose material transported by the floods cover the bottom of many otherwise feasible dam sites, but deposits of this character constantly imperil and shorten the life of all storage reservoirs. The flood waters bear this along, and when brought to rest drop the heavier material at first and then the lighter, retaining only the finest particles, the greater part of which in time may settle within the interstices of the coarser. Thus the upper ends of all reservoirs are rapidly filled with silt, and it becomes an important question to the projectors of storage works as to how many years will elapse before the value of the reservoir is practically destroyed and whether its use can be restored in part by subsequent removal of some of this material.

The legal obstacles are in many localities no less vexatious than those offered by nature. While many principles have been settled in regard to the use of water for irrigation, their application to particular cases is still a matter of doubt. Even in the case of persons diverting water from perennial streams there are innumerable controversies whenever a shortage occurs. But when a portion or all of the surplus water is being held in reservoirs and returned perhaps to the same stream, to be again recovered, there can not fail to be still greater complications than those now brought to the attention of the courts. The primary cause of most of the contentions which arise is the lack of exact knowledge concerning the amounts of water which are flowing in the streams from day to day and the quantities taken out by different canals. These are not only fluctuating, but the matter is complicated by the disappearance of water by evaporation and the reappearance of other waters in the natural drainage lines by seepage from canals above, or from the slow progress of water coming originally from rainfall and finding its way gradually toward the lowest points.

When one has noted the interminable lawsuits over water rights and appreciated the fact that most of these are due to lack of precise knowledge as to past conditions, it appears almost incredible that greater care is not being taken to ascertain exactly how much water is flowing at different points in the natural streams, especially in view of the fact that later large investments are to be made in storage projects. It is, however, a lamentable fact that very little attention is given to this matter, mainly perhaps because the persons investing in irrigation works are usually from humid climates, and it never occurs to them that rivers do not always have water to spare within their channels. Yet in southern Arizona, where, as in other portions of the arid regions, the rivers at certain seasons of the year diminish and even cease flowing, enormous investments are being made upon crude assumptions as to the quantity of water available, these assumptions being supported only by a few isolated facts or measurements.

The determining point in the construction of storage works, after their feasibility has been settled upon, is whether they will pay—whether the value of the water thus obtained and the benefits derived are sufficient to make the projects remunerative. The answer to this question depends largely upon what may be considered as profitable; for example, if these storage reservoirs are under consideration by corporate enterprise, it will be necessary to show that the annual water sales or rentals will not only repay the expense of management and a fair interest on investment, say 6 or 8 per cent, but will also yield a surplus which can be used as a sinking fund to repair damages or ultimately cover the cost of the works, should these be gradually deteriorated by accumulation of silt. The aggregate of these items is large and may amount to 10 per cent or upward. Thus it is necessary to show that the storage works will, after completion, pay for themselves within a brief period; otherwise individual capital will not be attracted.

If, on the other hand, these reservoirs, or the best of them, are built by the whole community interested or by State or national funds, the question of immediate profit does not enter so largely into the calculations. In this latter case the indirect benefits to be derived by the people offset to a certain extent the interest charge, and if the works can be shown to pay the cost of maintenance and provide a small sinking fund, they may be considered as feasible. Thus it is that a project which will be condemned by the investor as worthless may at the same time be of the utmost value to the community and one which would well repay cost of construction if this cost were distributed uniformly to all benefited.

The situation in the Salt and Gila river valleys is fairly typical of that elsewhere as regards the probable profits to be obtained by constructing storage reservoirs. Briefly stated, it may be said that the canal systems already constructed or partially completed cover a larger area of land than can be supplied by the average summer flow of the streams. Water from reservoirs is needed for lands already under ditch and whose owners have already purchased water rights. There are above these ditches still larger tracts of land which would be valuable if water could be had, but it is apparent that the greatest good would result from securing an ample supply of water to the lands already partly cultivated rather than indefinitely increasing the area of poorly watered farms.

If a corporation contemplates building a reservoir within the Gila Basin, the first question is, Shall the attempt be made to sell the water to lands already under ditch, or shall this water be taken to areas now desert? The former plan would be perhaps the best for all concerned; but experience has shown that there is no certainty that the owners of lands now partly supplied with water will purchase additional water rights, even though these would assure an ample supply at all times. This is due partly to the fact that many of these lands now under ditch are held by speculators, hoping for a general rise in land values—such a rise as will follow the construction of storage works. In other cases the lands are held by farmers, who, although cultivating a considerable part of their land, hesitate about purchasing additional water rights, preferring to try to get along with a deficient supply rather than risk additional outlay. Thus it has happened that similar enterprises of this character, where the water was apparently in great need, have been forced into bankruptcy by the accumulation of interest and maintenance charges during the period following construction and before the water rights could be sold to bona fide irrigators.

By the construction of storage works commanding the valley lands, there necessarily results an increase in value of every acre even though water rights have not been purchased, from the fact that there is a possibility of purchasing these. Upon the completion of such works, there takes place what is termed an unearned increment of value of all lands, for with the assurance of a larger supply even to other portions of the valley the chances of securing water in one way or another are increased. This increment of value is in round numbers equivalent to the cost of the storage works, and if it could be transferred from the pockets of the recipients, who have done nothing to deserve it, to the hands of the persons who have built the works, accounts would be balanced and it would be possible to construct these great enterprises. As a matter of fact, however, the association or group of men who build a reservoir must look to voluntary purchases by individuals slowly purchasing water rights for lands already owned or must seek reimbursement by putting the water upon desert lands and selling land and water.

This latter method, that of a storage company selling land and water together, is apparently the only feasible mode of procedure. It necessitates, however, not only the acquisition of reservoir site and expensive construction of storage works, but also, as a rule, the building of canal lines and the acquisition of large bodies of desert land, the latter being a contingency for which the land laws of the United States make no provision. If by one means or another such lands can be secured, directly or indirectly, the question of profit rests mainly upon the ability to dispose of these lands at a rate sufficiently rapid to prevent the accumulation of such indebtedness as often sweeps away a newly completed project. The tendency is, therefore, to extend irrigation by stored waters to new areas where land can be obtained at a nominal price and sold at a sufficient advance to repay the cost of construction, rather than attempt to supply water to lands already under ditch and partly irrigated.

Some of the best storage projects, however, are so situated that the water can not be taken readily to new areas, and it appears probable that these, although among the most important in the country, can only be constructed by the adoption of some scheme by which all of the lands of the valley benefited directly or indirectly will be forced to contribute an amount equal to the benefits derived. This is possible only under some system similar to that of the district organization in California, where all of the lands receiving water from a given source are assessed. Here it is not necessary to consider whether the enterprise will be money making in itself. Thus it is possible to push forward the construction of beneficial works which otherwise never could be built.

F. H. N.

THREE-YEAR-OLD ALMOND GROVE NEAR PHŒNIX, ARIZONA.

IRRIGATION NEAR PHŒNIX, ARIZONA.

BY ARTHUR P. DAVIS.

TOPOGRAPHIC FEATURES OF ARIZONA.

The Territory of Arizona covers approximately 113,000 square miles, of which about 39,000 lie below the altitude of 3,000 feet, about 27,000 lie between the contours of 3,000 and 5,000 feet, and about 47,000 lie above the elevation of 5,000 feet. The highest point in the Territory is San Francisco Mountain, in the northern part, which reaches an altitude of nearly 13,000 feet. The Territory is sharply divided into two characteristic portions by the trend across it of the main axis of the great Colorado Plateau, from the northwestern corner of the Territory in a nearly southeasterly direction. This plateau slopes gently to the northward, but on the southwestern side breaks off suddenly throughout most of its course, and its steep slope is deeply carved by lines of erosion. Almost the whole of that portion of the Territory which is below an elevation of 3,000 feet lies to the southward of this escarpment.

To the north of the escarpment the temperature ranges from that of the temperate zone to that where snow is nearly perpetual, on the summits of the San Francisco and White mountains. The southern portion of the Territory is characterized by temperatures which may be designated as ranging from temperate, along the foothills of the Colorado Plateau, to semitropic, in the lower valley of the Gila and Colorado. The southern portion of the Territory may be again subdivided into two portions, that draining directly into the Colorado and lying to the westward of Prescott, and the greater portion to the south and east, which forms the great Gila river system. The Colorado Plateau is partly of igneous origin, and a great portion of it is somewhat pervious to water. Its northern slope for a considerable distance from the summit is very gentle, and though the precipitation is greater than in most portions of the Territory, it is very meagerly marked by drainage lines and almost destitute of water. Sharply contrasted with these facts are the conditions on the southern slope. Here, through most of its course, the plateau drops off with a very steep slope, which is deeply cut with drainage lines in which are living creeks and rivulets of clear, beautiful water, such as San Francisco River, Black Creek, Bonito Creek, White River, Carrizo Creek, Cibicu Creek, Box Creek, Cherry Creek, Tonto Creek, Wild Rye Creek, East Verde River, Pine Creek, Fossil Creek, Clear Creek, Beaver Creek, etc.

The region of high altitude, as before remarked, lies largely north of the divide, while the great bulk of the water flowing from the plateau, as proved both by erosion of drainage lines and by the volume of permanent streams, flows away to the south. The explanation of this is partly the porosity of the strata composing the plateau, which allows the water to sink instead of flowing off the surface. Once underground, its egress to the south is favored by the shorter distance which it must percolate on a given grade before reaching a surface, due to the more abrupt slope.

Another partial explanation is found in the meteorological condition. The moisture of this region is brought from the Pacific Ocean and the Gulf of California by the prevailing southwest wind. As this wind ascends the elevations toward the Colorado Plateau, its temperature is lowered, which reduces its capacity for holding moisture and increases its relative humidity. When this quantity reaches 100 per cent in any part, precipitation occurs. This influence continues until the wind passes the summit, where the process is reversed.

As might be expected, therefore, the hydrographic resources of the country immediately southwest of the Colorado Plateau are disproportionately great when compared with those to the northward. For instance, the precipitation at Fort Apache, as shown by a mean of twenty years' observations, is 19.75 inches, the elevation being 5,050 feet, while the precipitation at Holbrook, at an elevation of 5,047 feet, on the northern slope, is 8.47 inches, as indicated by the mean of ten years' observations. This is an important fact, especially when taken in connection with the fact that the great areas of valley land with a semitropic climate lie in the southwestern portion of the Territory, and are easily covered by the streams which are formed by the conditions above described, and which constitute the main features of the great Gila river system.

GILA BASIN.

The drainage area of Gila River, including a number of small lost basins which are topographically tributary but which seldom or never furnish any run-off to the main stream, is about 72,000 square miles, of which nearly 57,000 lie in the Territory of Arizona, about 14,000 in New Mexico, and something over 1,000 in Mexico. The areas in the United States are distributed, with respect to elevation, approximately as follows:

Distribution of area of Gila Basin by altitude.

Elevation.	Per cent of area of basin.	Area, square miles.
Under 1,000 feet	9	6,400
Between 1,000 and 2,000 feet	19	13,500
Between 2,000 and 3,000 feet	16	11,400
Between 3,000 and 4,000 feet	14	10,000
Between 4,000 and 5,000 feet	15	10,700
Between 5,000 and 6,000 feet	12	8,500
Between 6,000 and 7,000 feet	8	5,600
Over 7,000 feet	7	4,900
Total	100	71,000

Gila Basin is conveniently divided into four parts. Of these, the most northerly is Salt River Basin, which includes all the territory tributary to Salt River. This again is sharply divided into its valley and mountain portions. Salt River Valley (see map, Pl. XXX) may be taken as including all the territory adjacent to Salt River from its mouth up to the junction of the Rio Verde. Above that point the greater portion of the basin is mountainous, with small valleys on the Rio Verde, in Tonto Basin, and at a few points on Salt River and other tributaries. The Lower Gila district may be taken as the portion lying below the mouth of Salt River; the Middle Gila district, that portion from the mouth of Salt River to The Buttes above Florence and including the Pima Indian Reservation and the great Casa Grande Valley. The Upper Gila district includes the valley in the region of Camp Thomas and Solomonsville and the tributary mountainous districts. In addition to these main divisions of the trunk streams may be taken the subordinate divisions of tributaries, such as San Pedro, Santa Cruz, Hassayampa, and Agua Fria creeks.

TEMPERATURE.

The tables of temperature for the Gila and Salt River valleys show that the climate is very warm. But care should be taken not to exaggerate this feature, for the actual conditions in their relation to human life and comfort are by no means as unfavorable as they might appear to persons comparing these tables of temperature with those of some Eastern localities. For about eight months in the year the temperature of this valley is delightful. Cool nights, bracing mornings, and bright, pleasant days are the rule, except in the months of June, July, August, and September. In these months the heat becomes intense, and though there is of course some variation, the temperature remains continually high throughout the greater part of this period.

The physiological effect of this heat is markedly modified by the aridity of the climate. The human economy provides that when the temperature of the healthy body rises above the normal the perspiratory glands begin to act and furnish the skin with moisture, the evaporation of which lowers the temperature of the body. An essential condition of this natural safeguard against excessive heat depends upon the ready evaporation of the moisture furnished by nature. In a very humid climate this evaporation can not occur; and in those portions of the country where the humidity is comparatively high such evaporation must be proportionately tardy and sluggish, so that any considerable temperature above normal blood heat produces great suffering and exhaustion, and even prostration. In an arid region, on the contrary, the low percentage of humidity causes prompt and quick evaporation of the moisture and the consequent success of nature in its attempt to prevent uncomfortable and injurious bodily temperature. In southern Arizona these favorable conditions for resistance to heat are at their maximum. Though the temperature is high, the relative humidity is very low, and every particle of moisture which reaches the surface of the skin is promptly evaporated—so promptly that its presence is not perceived—and while the body is thus kept at its normal temperature the unpleasant effects of excessive moisture are not experienced, and the sultry, sticky days so common in the East are unknown in Arizona.

The principles involved in these facts are frequently illustrated to the sojourner in southern Arizona in the following manner: Riding in a wagon or buggy in the month of July the traveler may feel greatly oppressed and enervated by the intense heat; the climate seems well-nigh insupportable; but if he will get out and walk for a short time, the circulation induced by the exercise starts the perspiration and the traveler is surprised to find himself greatly refreshed, and he may then resume his ride in comfort. Farm labor, the construction of canals, the rounding up and branding of cattle, and other active, hard labor are performed at any time in the summer with less comfort, of course, but with no worse effects, than at any other time of year, and without actual suffering, the only requisite being plenty of drinking water.

A fair comparison of the sensible temperatures of two places may be obtained by a comparison of the readings of wet-bulb thermometers. The difference between the readings of wet and dry bulb thermometers here often exceeds 30 degrees. The summer is, therefore, far from being as uncomfortable as might be supposed, and the delightful autumn, winter, and spring fully compensate for the discomforts of the summer months; and the climate, taken as a whole, with its extreme aridity, its mildness, and its large proportion of sunshine, is exceptionally healthy and especially beneficial to those suffering from bronchial or pulmonary troubles.

RAINFALL.

Rainfall records of Arizona, from the date when they began up to and including the summer of 1890, were prepared by Capt. William A. Glassford and published in a Report on the Climatology of the United States, with Reference to Irrigation, by Gen. A. W. Greely, Chief Signal Officer.[1] Later records may be found in the various annual and monthly publications of the Weather Bureau, and it is deemed of value to reproduce some of them here, brought up to date, partly because of the scattered condition of the original records, some of them being now out of print, and partly for the reason that for purposes of irrigation the season is best divided about the end of August. Rainfall occurring after September 1 can not in most cases be relied upon for irrigation use in that season, but may be stored for use in the following year. Precipitation occurring before this date may usually be utilized the same year, especially if storage is provided.

No arbitrary line can be drawn separating the precipitation available in one year from that available only by storage for the next, but it is thought that more cases will occur where September precipitation can be used the same year than where August precipitation can not, and that it is fair to divide the season as above indicated. For the convenience of those contemplating storage works, therefore, the tables are rearranged and the total annual rainfalls recomputed on this basis. A glance at the annual and monthly means shows at once that agriculture in the valleys of southern Arizona must depend entirely upon irrigation.

Short fragmentary records in Arizona are of very little value, on account of the erratic nature of Arizona rainfall, which is peculiarly marked during the summer rainy season. This season is characterized by sudden violent local thundershowers, often called cloudbursts, and while in a long series of years such local storms probably distribute themselves with a fair degree of uniformity over districts governed by the same general conditions, yet a short record may be so affected by them as to be abnormal. A station receiving one or more storms of this character, or being avoided altogether, as is likely to occur in a short record, may give results that will be very misleading. For instance, at Fort Lowell, which is but 9 miles east of Tucson, and only 4 feet lower, there fell during July and August, 1878, 0.60 and 7.88 inches of rain, respectively, while at Tucson during the same months the rainfall was 5.72 and 4.71 inches. Such discrepancies would probably disappear

[1] Fifty-first Congress, 2d session, H. R. Ex. Doc. No. 287, Irrigation and Water Storage in the Arid Regions.

in the average of a long series of observations. Very short records, on account of the great secular variations even in countries of greatest uniformity, can not be depended upon as giving the average rainfall for the region in which they are taken. In this climate, for the reasons given above, they are of little, if any, value, even when a long record exists in such situation that a comparison of its mean with that of the short record may be made.

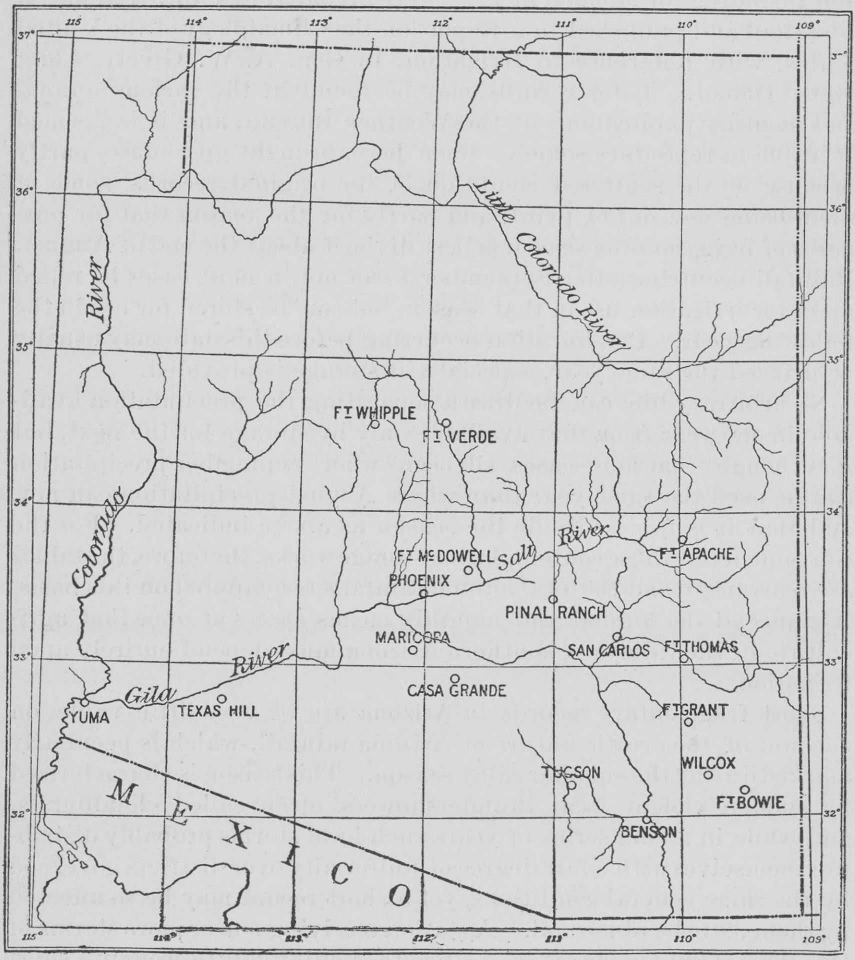


FIG. 1.—Map of Arizona, showing location of rainfall stations.

In a region like Arizona, where the water supply bears such a vital relation to its prosperity, and where, moreover, the means available for keeping rainfall records are limited, rainfall stations should be, and usually are, so far as practicable, widely distributed over the Territory, in order that all varieties of elevation, topography, latitude, and climatic conditions may be represented. Such records, if carefully kept for a long series of years, say twenty or more, become valuable for determining the actual rainfall to be expected in any particular locality by means of a short record embracing four or five years. The comparison of such short record with the synchronous record at the station of long observation establishes an approximate relation between the point under investigation and the point at which the long record was taken. In a similar manner a comparison may be made between the measured discharge of any given stream and the synchronous rainfall at the old station, and in a few years a relation can be thus established from which may be derived an approximate hypothetical history of the stream or hydrographic basin under investigation.

The value of these old records, which, unfortunately, are very rare, depends chiefly upon their continuation. It may be broadly stated that the older such a record becomes the stronger is the argument for continuing it. It is especially to be deplored, therefore, that some of the old records in Arizona have been discontinued. For instance, Fort McDowell, having in 1891 the oldest continuous record in Arizona, was in that year discontinued, and has not since been resumed. A great part of the value of this old record might be restored if it were practicable to reestablish the station.

A selection has been made of 16 stations, most of them having a record covering at least fifteen years, so distributed as fairly to indicate the means and extremes of precipitation in the various portions of the basin. A short record at Pinal ranch, not hitherto published, is also included. These records are contained in the following tables:

Record of precipitation at Fort Whipple, Yavapai County.

[Latitude 34° 33′, longitude 112° 28′; elevation, 5,389 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1866–67	3.65	0.57	0.08	0.31	1.72	1.16	8.00	0.06	1.17	0.00	2.70	2.38	21.80
1867–68	......	0.10	0.20	2.20	2.97	5.30	0.50	1.00	......	0.00	6.16	2.72	....
1868–69	0.30	0.55	1.50	4.40	0.80	0.92	......	......	......	......	......	......	....
1869–70	[1.08]	1.40	1.45	0.00	0.00	1.20	1.09	0.26	1.73	0.24	7.98	3.49	19.92
1870–71	0.00	1.59	0.30	0.53	0.70	1.01	0.10	1.92	0.47	0.00	4.00	1.80	12.42
1871–72	1.51	1.40	0.52	0.00	0.50	0.80	0.12	1.62	1.47	1.24	3.74	6.25	19.17
1872–73	0.04	0.24	0.00	0.64	0.00	1.00	0.23	0.17	0.40	0.42	1.56	4.78	9.48
1873–74	0.30	0.00	0.80	2.55	5.51	5.68	3.56	1.70	0.65	0.00	5.72	1.56	28.03
1874–75	0.00	0.50	......	......	......	......	......	......	0.00	0.00	5.92	1.66	....
1875–76	0.77	0.00	0.18	0.63	4.60	0.01	0.83	0.51	0.52	0.25	3.28	4.51	16.09
1876–77	0.72	0.93	0.00	0.00	0.36	0.56	0.49	1.50	1.82	0.00	1.29	0.24	7.91
1877–78	2.42	1.36	0.00	2.23	0.28	2.02	0.48	2.86	0.33	0.33	0.91	6.34	19.56
1878–79	0.61	0.00	0.45	1.02	0.91	0.94	0.05	0.03	0.00	0.05	1.87	2.20	8.13
1879–80	0.68	0.37	1.58	4.21	0.35	0.16	0.11	0.52	0.00	0.04	2.34	2.80	13.16
1880–81	1.26	0.18	0.42	1.84	0.16	0.10	2.91	0.67	0.42	T.	3.27	5.25	16.48
1881–82	1.69	0.33	0.30	0.33	2.53	2.04	0.00	0.28	0.45	0.47	1.64	3.34	13.40
1882–83	2.57	0.39	1.55	0.00	0.31	0.63	2.33	0.86	0.15	0.09	3.20	3.26	15.34
1883–84	0.33	0.43	T.	4.54	0.25	6.55	5.51	1.62	1.45	0.32	1.33	1.57	23.90

Record of precipitation at Fort Whipple, Yavapai County—Continued.

[Latitude 34° 33′, longitude 112° 28′; elevation, 5,389 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1884–85	0.99	1.42	0.16	5.58	0.08	0.46	1.47	0.62	0.37	0.07	2.53	1.24	14.99
1885–86	0.11	0.38	2.46	0.32	5.99	1.15	3.04	1.18	0.03	0.00	0.61	4.41	19.68
1886–87	0.46	0.23	1.68	T.	T.	3.12	T.	2.57	0.43	0.57	2.64	0.71	12.41
1887–88	4.88	0.05	1.57	0.82	1.30	1.68	1.66	0.52	1.96	0.00	2.49	1.42	18.35
1888–89	0.62	1.75	3.18	2.94	1.73	1.35	2.91	0.19	T.	0.02	1.45	1.51	17.65
1889–90	2.11	1.76	0.42	7.38	2.29	3.02	1.52	0.86	0.00	0.06	2.19	2.67	24.28
1890–91	1.48				0.00	5.96	0.86	T.	0.27	0.00	1.86	3.04	
1891–92	1.48	0.00	0.00	1.19	1.98	1.64	1.91	0.58	0.85	0.00	1.74	2.04	13.41
1892–93	0.14	1.41	0.00	0.61	1.18	0.47	3.26	0.00	0.88	0.00	1.31	4.30	13.56
1893–94	0.57	0.15	1.16	0.73	0.30	0.30	0.88	0.00	0.23	T.	1.13	3.88	9.33
1894–95	0.45	1.37	0.00	3.43	4.37	0.55	T.	0.25	0.50	0.00	0.88	3.53	15.33
1895–96	0.09	0.24	3.59	0.50	0.55	0.20	0.81	0.35	T.	0.14	4.70	2.61	13.78
Mean	1.08	0.66	0.84	1.75	1.44	1.10	1.59	0.81	0.59	0.15	2.77	2.95	16.06

Record of precipitation at Fort Verde, Yavapai County.

[Latitude 34° 32′, longitude 111° 47′; elevation, 3,160 feet. Authority, Signal Service and United States Hospital Service.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1868–69				0.27	0.34	1.72	1.00	0.09	0.03	0.83	0.07	7.26	
1869–70	0.00	0.02	4.04	0.00	0.50	0.01	0.50	0.15	0.00	0.22	3.06	0.89	9.39
1870–71	0.00	0.60	0.10	0.58	0.20	0.00	0.04	0.73	0.00	0.00	0.84	0.26	3.35
1871–72	1.00	1.10	0.39	0.26	0.47	1.12	0.16	1.56	0.54	0.22	2.22	4.35	13.39
1872–73	1.12	0.10	0.00	0.83	0.00	1.16	0.00	0.00	0.15	0.20	0.14	2.52	6.22
1873–74	0.26	0.00	0.74	3.26	2.65	2.05	1.05	1.48	0.08	0.00	1.88	2.48	15.93
1874–75	0.00	1.45	3.52	0.66	2.91	0.05	0.30	T.	0.06	0.00	3.33	2.01	14.29
1875–76	1.35	0.00	0.65	0.13	2.06	0.75	1.00	0.75	0.00	0.98	5.31	12.08	25.06
1876–77	2.40	2.10	0.15	0.00	0.71	0.51	0.89	0.85	1.70	0.00	0.70	0.41	10.42
1877–78	2.08	0.45	0.05	2.23	0.14	1.12	1.84	1.75	0.16	0.06	2.10	4.60	16.56
1878–79	0.98	0.00	0.36	1.24	0.20	0.14	0.00	0.10	0.00	0.00	0.97	0.53	4.52
1879–80	1.40	0.23	2.40	3.03	1.08	0.13	0.30	0.27	0.00	0.16	1.85	0.97	11.82
1880–81	0.19	0.57	0.13	1.56	0.07	0.12	2.64	0.97	0.07	T.	1.41	7.53	15.26
1881–82	1.88	0.20	0.21	0.27	2.72	0.93	0.01	0.03	0.19	1.35	1.25	1.18	10.22
1882–83	2.16	0.25	1.73	0.07	0.44	1.35	1.63	0.12	0.27	0.04	3.35	1.14	12.55
1883–84	0.00	0.45	0.00	4.30	0.39	3.59	3.60	1.43	0.72	0.23	0.19	1.24	16.14
1884–85	0.68	0.84	0.15	4.66	0.00	0.80	2.25	0.69	0.19	0.05	0.84	3.01	14.16
1885–86	0.03	0.61	1.88	0.52	1.90	1.48	2.09	0.82	0.02	0.01	0.18	3.18	12.72
1886–87	0.20	0.13	0.55	0.60	0.04	0.78	0.02	0.58	0.60	0.18	3.11	2.96	9.75
1887–88	4.72	0.00	1.37	0.87	0.96	1.56	1.78	0.43	0.96	0.00	2.21	0.73	15.59
1888–89	0.56	4.47	2.80	3.15	1.95	0.25	1.66	0.00	0.00	0.02	3.10	0.75	18.71
1889–90	1.60	1.74	0.08	5.08	1.39	1.97	1.35	0.82	0.01	0.00	1.83	2.30	18.17
1890–91	0.55	[1.50]	[3.65]	[1.72]									
Mean	1.05	0.76	1.13	1.53	0.96	0.96	1.10	0.62	0.26	0.21	1.82	2.84	13.24

Record of precipitation at Fort McDowell, Maricopa County.

[Latitude 33° 38′, longitude 111° 38′; elevation, 1,250 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1866-67	1.63	0.25	0.06	0.10	0.88	0.16	2.11	0.03	0.00	0.00	2.97	1.18	9.37
1867-68	1.62	0.03	0.29	5.70	2.70	1.60	0.70	[1.00]	0.00	0.00	4.50	1.70	19.84
1868-69	3.01	T.	0.01	0.00	0.64	2.60	0.00	0.15	T.	0.10	0.40	1.10	8.01
1869-70	0.00	0.00	2.15	0.55	T.	0.60	0.65	T.	T.	0.70	0.90	1.98	7.53
1870-71	0.22	0.40	0.00	T.	0.25	0.40	0.00	0.40	T.	T.	0.16	2.08	3.91
1871-72	0.20	0.00	1.25	0.20	0.50	0.40	0.00	0.53	0.30	0.31	9.16	7.17	20.02
1872-73	0.08	T.	0.00	1.56	0.00	1.60	0.90	0.00	0.16	T.	T.	0.56	4.86
1873-74	0.60	T.	0.21	4.70	3.10	2.86	1.06	1.30	0.30	0.00	1.31	1.99	16.83
1874-75	0.05	1.11	2.76	1.00	1.40	0.62	T.	0.10	T.	0.00	0.75	0.46	8.25
1875-76	1.00	0.00	0.00	0.64	0.70	0.10	0.40	T.	0.00	1.00	3.25	1.70	8.79
1876-77	0.00	T.	0.58	0.00	1.08	2.24	0.44	0.50	1.04	0.00	T.	0.06	5.94
1877-78	1.52	0.38	T.	2.12	0.04	1.54	1.18	3.20	T.	T.	0.86	1.57	12.41
1878-79	0.98	0.00	0.99	1.56	0.50	1.22	0.60	0.20	0.00	0.00	T.	0.12	6.17
1879-80	0.34	0.58	2.14	2.64	1.56	0.38	0.50	0.38	0.00	T.	0.52	0.84	9.88
1880-81	0.34	[0.40]	0.00	1.69	T.	T.	1.46	0.22	0.12	0.00	1.16	3.38	8.77
1881-82	0.10	T.	0.80	T.	3.22	0.58	0.00	T.	0.10	0.56	0.40	1.52	7.28
1882-83	1.34	0.00	1.38	0.00	0.59	0.78	0.42	0.00	0.28	0.04	1.12	1.76	7.71
1883-84	0.32	0.30	0.06	4.22	0.33	4.37	3.47	0.58	0.45	0.09	0.08	1.25	15.52
1884-85	3.96	1.38	0.45	4.54	0.00	2.50	0.60	0.00	0.00	0.00	0.00	0.90	14.33
1885-86	0.90	0.40	1.75	1.25	3.35	1.60	1.50	T.	0.00	[0.00]	0.00	0.62	11.37
1886-87	T.	0.27	0.44	0.30	0.00	0.86	0.00	0.68	T.	0.00	0.06	1.54	4.15
1887-88	4.11	0.48	1.82	0.77	0.87	0.72	0.62	0.14	0.40	0.00	0.86	0.17	10.96
1888-89	0.35	2.82	1.49	3.47	2.85	0.77	0.14	0.09	0.00	0.06	0.62	0.29	12.95
1889-90	0.61	1.31	0.73	5.31	0.89	1.37	0.96	0.55	0.00	0.00	1.10	1.55	14.38
1890-91	0.26	1.07											
Mean	0.94	0.45	0.81	1.76	1.06	1.24	0.74	0.42	0.13	0.12	1.26	1.48	10.39

Record of precipitation at Fort Apache, Navajo County.

Latitude 33° 48′, longitude 109° 57′; elevation, 5,050 feet. Authority, Signal Service and United States Hospital Service.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76					0.92	1.72	2.02	0.08	0.26	1.02	5.20	2.52	
1876-77	2.00	2.44	1.34	0.22	0.36	0.94	0.72	0.96	1.15	0.00	3.11	1.20	14.44
1877-78	0.99	0.81	0.19	2.07	0.18	1.35	2.41	1.77	0.18	0.79	8.76	9.33	28.83
1878-79	0.76	0.00	1.94	1.14	1.89	1.17	0.03	0.12	0.00	0.05	3.92	3.06	14.08
1879-80	1.52	2.64	1.77	2.41	1.31	0.95	0.80	0.46	0.00	0.46	5.83	1.44	19.59
1880-81	0.55	0.56	0.03	2.38	0.20	1.17	2.45	1.53	0.35	T.	5.63	8.31	23.16
1881-82	5.41	4.68	0.85	0.54	2.82	2.85	1.09	0.91	0.94	3.27	4.79	7.36	35.51
1882-83	1.02	T.	2.34	0.23	0.85	2.46	2.03	0.22	0.86	0.02	5.46	4.26	19.75
1883-84	0.60	1.39	0.02	3.48	0.68	3.43	4.44	1.67	1.31	2.35	0.14	5.59	25.10
1884-85	1.50	2.02	0.82	5.52	0.52	1.00	2.05	0.52	1.12	0.82	2.60	3.16	21.65
1885-86	0.44	0.38	1.56	1.41	3.90	2.73	1.06	0.91	0.00	0.19	1.90	4.75	19.23
1886-87	3.16	1.66	0.56	0.24	0.59	2.16	0.04	0.81	0.15	1.70	3.29	3.92	18.28
1887-88	2.23	0.55	1.83	0.57	1.42	1.83	2.92	0.71	0.71	T.	3.24	[1.00]	17.01
1888-89	0.32	1.23	2.63	2.88	2.24	0.88	1.85	0.47	0.00	0.11	2.67	2.87	18.15
1889-90	1.02	0.46	0.55	3.98	2.26	2.40	0.82	1.39	0.00	0.00	5.00	4.44	22.32
1890-91	2.37	2.17	2.85	3.02	1.65	4.10	0.85	T.	0.36	T.	2.72	1.22	21.31
1891-92	1.81	0.00	0.00	0.65	0.65	2.29	2.22	1.36	0.36	0.15	1.33	1.30	12.12
1892-93	1.23	0.55	0.57	0.69	0.28	1.10	2.45	0.00	2.18	0.00	2.57	3.43	15.05
1893-94	2.65	0.04	0.28	0.10	1.24	0.96	1.36	0.19	0.79	0.00	1.27	5.01	13.89
1894-95	1.32	2.47	0.00	2.81	1.89	0.72	0.02	T.	1.00	0.01	0.74	5.44	16.42
1895-96	1.68	3.02	2.39	1.12	0.16	0.33	0.86	0.34	0.00	0.52	4.31	4.36	19.09
Mean	1.63	1.35	1.13	1.77	1.23	1.74	1.55	0.69	0.56	0.55	3.55	4.00	19.75

Record of precipitation at Pinal Ranch, Pinal County.

[Latitude 33° 25′, longitude 110° 58′; elevation, 4,400 feet. Authority, Irion and Craig.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1891-92	------	------	------	------	------	------	------	------	------	------	0.00	0.81	---------
1892-93	0.15	0.90	0.43	0.99	0.92	1.57	5.21	0.00	1.44	0.00	2.86	3.69	18.16
1893-94	4.13	0.00	1.66	0.83	1.23	1.81	1.93	0.00	0.14	0.00	1.63	2.87	16.23
1894-95	0.32	1.19	0.00	7.77	7.28	1.06	0.31	0.00	0.36	0.00	0.63	5.88	24.80
1895-96	2.04	4.78	5.33	1.52	1.10	0.18	1.05	0.50	0.00	0.24	4.04	2.90	23.69
1896-97	3.47	3.42	2.35	1.13	------	------	------	------	------	------	------	------	---------
Mean	2.02	2.06	1.95	2.45	2.63	1.16	2.13	0.13	0.48	0.06	1.83	3.23	20.46

Record of precipitation at Phœnix, Maricopa County.

[Latitude 33° 28′, longitude 112° 00′; elevation, 1,068 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76	------	------	------	------	------	0.82	0.27	0.00	0.00	------	------	[1.00]	---------
1876-77	0.90	0.72	0.00	0.00	0.60	1.63	0.31	0.00	0.00	0.00	[1.00]	0.02	5.18
1877-78	1.11	0.04	0.03	0.43	0.07	1.07	0.96	1.25	0.04	0.00	2.40	1.63	9.03
1878-79	0.19	0.00	0.27	0.64	0.07	0.75	0.33	0.07	0.00	0.00	0.54	0.67	3.53
1879-80	0.69	0.27	1.66	1.35	1.16	0.38	0.26	0.15	0.00	0.49	1.18	0.72	8.31
1880-81	0.67	0.20	0.00	1.61	0.00	0.20	1.46	1.10	0.12	0.00	2.03	2.19	9.58
1881-82	1.04	0.25	0.36	0.16	1.62	0.17	0.00	0.00	0.00	0.37	0.32	1.81	6.10
1882-83	1.25	0.10	1.30	0.00	0.83	1.27	1.16	T.	0.44	0.00	0.07	0.07	6.49
1883-84	0.00	0.20	0.00	3.36	0.16	2.46	2.14	0.40	0.01	0.15	0.07	1.84	10.79
1884-85	1.50	1.12	0.24	2.74	0.00	0.47	0.33	0.00	0.65	0.04	0.18	0.71	7.98
1885-86	0.07	0.09	0.91	0.32	1.32	1.25	1.86	0.29	0.00	0.00	0.05	0.59	6.75
1886-87	0.45	0.58	0.32	0.07	0.00	0.28	T.	0.75	0.06	0.00	------	------	---------
1887-88	------	------	------	[0.50]	------	------	------	0.01	0.30	0.00	0.13	0.27	---------
1888-89	0.23	[2.80]	1.10	[3.00]	------	------	------	------	0.00	0.12	0.66	1.77	---------
1889-90	0.39	0.99	0.77	3.38	0.95	0.52	1.18	0.51	0.00	------	------	------	---------
1891-92	------	------	0.00	0.13	1.85	2.20	0.60	0.70	0.15	0.00	0.00	0.00	---------
1892-93	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	1.00	0.00	3.20	[1.42]	6.08
1893-94	0.00	0.00	0.60	1.00	0.00	0.70	0.62	0.00	0.07	0.00	0.97	0 79	4 75
1894-95	0.15	0.77	0.00	1.43	------	------	------	0.00	------	------	------	------	---------
1895-96	------	------	1.22	0.07	0.48	0.00	0.28	0.00	0.00	0.00	3.66	1.05	---------
Mean	0.54	0.51	0.48	1.44	0.57	0.83	0.72	0.29	0.15	0.07	1.03	0.97	7.60

Record of precipitation at Fort Bowie, Cochise County.

[Latitude 32° 12′, longitude 109° 20′; elevation, 4,781 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1866-67	------	------	------	------	------	------	------	------	------	------	------	2.67	---------
1867-68	1.70	T.	0.50	1.64	2.39	1.10	0.00	0.70	0.50	0.00	7.15	2.40	18.08
1868-69	3.15	T.	0.70	0.00	0.10	3.50	0.39	0.15	0.00	0.40	1.30	5.60	15.29
1869-70	0.20	T.	1.45	0.15	0.30	0.69	0.50	T.	0.00	0.60	4.50	5.42	13.81
1870-71	1.00	0.00	T.	1.00	0.50	[1.00]	[0.50]	[0.60]	0.18	0.60	7.90	2.30	15.58
1871-72	1.00	0.70	0.90	[1.25]	[0.40]	[0.50]	0.00	0.25	0.20	1.04	1.67	3.36	11.27
1872-73	0.77	T.	0.15	2.95	0.00	1.16	2.22	T.	1.09	0.14	0.50	1.34	10.32
1873-74	0.01	0.03	1.12	2.02	2.33	5.40	1.50	0.35	0.00	T.	2.66	3.12	18.54
1874-75	0.06	1.40	1.45	0.46	1.35	1.20	0.13	0.13	T.	0.65	4.22	1.77	12.82

Record of precipitation at Fort Bowie, Cochise County—Continued.

[Latitude 32° 12′, longitude 109° 20′; elevation, 4,781 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875–76	3.19	0.00	0.25	0.83	0.60	0.45	0.48	T.	T.	2.05	4.55	4.00	16.40
1876–77	1.95	0.73	0.40	0.00	0.14	2.70	0.12	0.14	0.90	0.00	1.24	0.18	8.50
1877–78	1.16	0.00	0.00	2.04	[0.50]	0.50	2.83	1.00	0.20	0.20	4.92	7.44	20.79
1878–79	0.07	0.07	1.50	1.09	3.00	0.63	0.40	0.02	0.00	0.00	1.01	0.20	7.99
1879–80	2.00	0.60	0.10	0.50	0.25	1.40	1.45	0.15	0.00	1.50	4.80	0.97	13.72
1880–81	1.35	0.70	0.05	0.82	0.00	0.20	0.79	0.05	0.10	0.06	5.53	5.16	14.81
1881–82	2.27	1.15	0.58	0.03	0.90	1.15	1.51	0.26	0.71	1.39	3.58	4.84	18.37
1882–83	1.51	[0.00]	1.79	0.35	1.49	1.33	2.84	0.00	1.50	0.33	2.21	1.73	15.08
1883–84	0.72	0.20	0.39	1.12	3.14	4.96	2.63	0.00	0.23	0.12	0.65	2.44	16.60
1884–85	0.62	3.58	0.42	6.41	0.53	1.81	2.19	0.00	0.19	0.66	1.83	2.19	20.43
1885–86	0.44	0.00	1.42	1.74	4.24	4.88	4.48	0.07	0.01	4.21	2.24	2.49	26.22
1886–87	1.26	0.36	0.74	0.15	0.13	2.11	0.00	0.23	T.	1.30	4.49	5.51	16.28
1887–88	2.71	1.01	1.10	1.94	1.11	1.50	1.92	T.	0.46	0.53	2.50	1.37	16.15
1888–89	0.21	1.89	1.95	2.12	1.38	1.62	1.58	T.	0.09	0.09	2.65	0.20	13.78
1889–90	3.37	0.74	T.	0.51	0.78	0.23	0.03	0.59	0.00	T.	4.97	4.06	15.28
1890–91	1.74	1.60	0.61	2.45	0.69	2.18	0.65	0.00	1.38	T.	0.28	1.00	12.58
1891–92	0.61	0.00	0.00	1.26	0.81	3.36	1.62	0.41	0.00	0.50	1.12	2.65	12.34
1892–93	0.00	1.80	0.30	0.60	0.40	0.80	2.70	0.00	0.30	0.00	3.69	3.41	14.00
1893–94	1.06	0.04	0.07	0.25	0.65	2.55	1.07	0.01	T.	T.	1.07	4.80	11.57
1894–95	1.06	------	------	------	------	------	------	------	------	------	------	------	---------
Mean	1.26	0.59	0.66	1.25	1.04	1.81	1.28	0.19	0.30	0.61	3.08	3.95	16.02

Record of precipitation at Wilcox, Cochise County.

[Latitude 32° 20′, longitude 109° 42′; elevation, 4,164 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880–81	------	0.04	0.00	0.40	0.02	0.00	2.95	T	0.00	[0.00]	3.97	5.17	12.55
1881–82	0.00	0.00	0.00	0.00	[0.50]	1.15	0.00	0.00	0.00	[0.90]	0.11	3.46	6.22
1882–83	1.56	0.00	0.58	0.32	1.25	0.31	0.41	0.00	0.33	0.03	1.56	3.15	9.50
1883–84	0.04	0.30	0.36	0.99	0.80	1.61	1.75	0.00	0.00	0.04	1.17	1.54	8.60
1884–85	0.14	3.59	0.25	3.49	0.05	0.63	1.52	0.03	[0.20]	0.34	1.78	2.10	14.12
1885–86	1.11	0.00	0.56	0.19	[3.00]	[1.00]	0.15	0.01	0.00	T.	0.37	2.14	8.53
1886–87	1.68	0.36	0.58	0.08	T.	1.83	0.00	0.03	0.48	0.47	3.82	5.31	14.64
1887–88	2.96	0.45	0.22	0.92	0.36	1.21	1.13	0.03	0.14	0.08	3.68	0.42	11.60
1888–89	0.50	1.15	1.86	1.37	1.31	0.90	1.06	0.04	0.00	0.13	4.91	0.97	14.20
1889–90	2.91	0.83	T.	0.62	1.61	0.35	0.22	0.63	0.00	0.14	2.64	5.20	15.15
1890–91	1.97	0.54	0.43	0.72	0.54	2.45	0.26	0.00	0.87	0.07	T.	2.10	9.95
1891–92	0.22	0.00	0.00	0.85	0.05	1.45	0.84	0.25	1.02	2.00	0.97	0.94	8.59
1892–93	0.32	0.00	0.00	0.17	0.00	0.10	0.79	0.00	0.50	0.00	1.74	1.03	4.65
1893–94	0.93	0.00	0.00	0.00	0.50	1.37	0.77	0.00	0.00	0.00	0.00	1.52	5.09
1894–95	0.27	0.78	0.00	0.67	0.11	0.00	0.00	0.00	0.77	0.00	1.92	3.06	7.58
1895–96	0.11	0.08	1.59	0.40	0.27	1.03	0.05	0.00	0.00	0.00	1.46	1.77	6.76
Mean	0.98	0.51	0.40	0.70	0.65	0.96	0.74	0.06	0.27	0.26	1.88	2.49	9.90

Record of precipitation at Fort Grant, Graham County.

[Latitude 32° 36′, longitude 109° 53′; elevation, 4,860 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1872–73	------	------	------	------	0.00	0.10	1.00	0.00	0.50	1.40	1.70	5.20	9.90
1873–74	2.50	0.46	3.38	1.75	1.58	2.87	2.45	0.58	0.07	0.00	2.70	2.01	20.35
1874–75	0.00	1.47	0.30	3.78	2.48	1.44	1.95	1.52	0.00	0.50	7.02	1.08	21.54
1875–76	4.59	0.01	0.20	0.12	0.26	0.24	0.44	------	------	0.65	5.27	7.41	--------
1876–77	1.99	2.86	1.00	[1.42]	0.17	1.50	0.30	0.42	0.66	0.00	0.94	0.60	11.86
1877–78	2.88	0.50	0.00	2.16	0.23	0.50	0.37	0.18	0.00	0.32	6.44	4.93	18.51
1878–79	0.20	0.00	1.90	1.39	1.38	0.47	0.85	0.07	0.00	0.08	2.59	1.12	10.05
1879–80	2.18	1.83	0.87	1.38	0.60	0.48	0.85	0.08	0.00	1.32	5.63	3.73	18.95
1880–81	1.01	0.47	0.00	1.57	0.05	0.33	0.89	0.84	0.26	T.	5.53	5.47	16.42
1881–82	3.84	1.02	0.08	0.65	0.86	1.26	1.84	0.07	0.81	1.47	2.62	4.73	19.25
1882–83	0.80	0.00	0.79	0.17	1.21	1.40	1.27	0.03	1.16	1.26	2.90	3.07	14.06
1883–84	0.42	1.21	0.11	1.44	1.12	4.62	3.87	0.47	0.81	1.20	0.67	2.41	18.35
1884–85	0.98	3.06	0.53	5.93	0.31	1.02	1.40	0.04	0.25	0.73	0.93	1.58	16.76
1885–86	0.81	0.03	1.30	0.81	2.46	1.29	0.53	0.30	0.04	0.57	2.79	3.40	14.33
1886–87	3.49	0.57	0.10	0.09	0.11	2.58	T.	0.36	0.16	0.85	9.00	6.20	23.51
1887–88	4.20	0.37	0.28	0.21	0.12	0.44	0.83	0.50	0.18	0.02	4.27	0.52	11.94
1888–89	0.78	1.19	3.67	1.68	1.99	1.28	1.04	0.13	T.	1.06	3.57	1.35	17.74
1889–90	0.69	0.94	0.16	1.11	1.58	0.46	0.46	0.92	0.01	0.20	3.23	4.54	14.30
1890–91	0.69	1.62	0.16	2.01	0.82	3.78	0.28	0.00	1.40	0.10	1.19	2.25	14.30
1891–92	1.21	0.00	0.00	1.18	0.96	1.59	1.66	0.64	0.35	0.00	0.86	1.00	9.45
1892–93	0.11	0.46	0.12	0.15	0.56	0.59	1.26	0.00	0.58	0.00	4.24	2.00	10.07
1893–94	3.87	T.	0.40	0.35	0.38	3.43	0.66	0.13	0.37	0.00	2.55	1.98	14.12
1894–95	0.14	1.10	0.00	2.79	1.65	0.37	0.02	0.07	0.30	0.14	1.09	4.02	11.69
1895–96	1.69	1.21	2.05	0.61	0.29	0.50	0.34	0.26	0.00	0.90	1.88	2.68	12.41
Mean	1.70	0.89	0.76	1.42	0.88	1.36	1.02	0.33	0.34	0.53	3.32	3.05	15.45

Record of precipitation at Fort Thomas, Graham County.

[Latitude 33° 04′, longitude 109° 51′; elevation, 2,700 feet. Authority, United States Hospital Service and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1879–80	------	------	------	------	------	------	------	0.06	0.00	0.55	0.87	2.49	--------
1880–81	0.55	0.18	0.03	1.27	0.03	0.13	1.21	0.63	0.07	0.00	4.18	2.49	10.77
1881–82	1.55	0.40	0.32	0.40	0.33	1.01	0.70	0.02	0.47	1.26	0.88	2.48	9.82
1882–83	0.28	0.00	0.77	0.46	1.23	1.54	1.33	0.00	0.79	0.00	1.85	2.52	10.77
1883–84	T.	0.52	0.00	1.07	0.45	2.94	3.21	0.72	0.60	0.52	0.36	2.04	12.43
1884–85	0.91	0.69	0.56	5.16	0.03	1.00	0.75	0.14	0.09	0.18	2.93	2.46	14.90
1885–86	0.02	0.01	0.38	0.71	2.16	1.40	0.44	0.24	0.00	0.00	0.10	4.02	9.48
1886–87	1.18	1.12	0.16	0.04	0.09	0.84	0.00	0.31	2.73	0.35	3.78	2.53	13.13
1887–88	3.87	0.28	0.52	1.05	0.65	1.06	1.78	0.37	0.23	0.00	1.88	0.64	12.33
1888–89	0.55	2.80	1.72	1.66	1.47	1.35	0.96	0.10	0.00	T.	3.45	1.40	15.46
1889–90	0.38	0.26	0.34	1.18	1.92	0.49	0.45	1.21	0.00	T.	2.02	4.11	12.36
1890–91	0.75	1.30	0.69	0.99	0.72	2.98	0.40	0.00	1.61	0.18	------	------	--------
Mean	0.91	0.69	0.50	1.27	0.83	1.34	1.02	0.32	0.55	0.25	2.03	2.47	12.18

Record of precipitation at San Carlos, Gila County.

[Latitude 33° 12′, longitude 110° 27′; elevation, 3,456 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880–81	------	------	------	------	------	------	------	------	------	0.00	4.13	5.93	---------
1881–82	1.94	0.93	0.06	0.52	1.24	0.93	0.55	0.00	0.71	1.09	1.98	6.05	16.00
1882–83	0.58	0.00	1.58	0.66	1.60	2.07	0.71	0.00	0.53	0.00	2.48	1.11	11.32
1883–84	0.11	1.13	0.00	2.47	1.00	3.83	3.97	0.84	0.32	0.49	0.37	1.24	15.77
1884–85	0.83	1.49	0.55	5.48	0.05	1.39	1.28	0.03	0.22	0.47	1.25	1.22	14.26
1885–86	0.34	0.34	0.70	0.90	2.88	1.29	0.82	0.14	0.00	0.00	0.03	3.49	10.93
1886–87	0.87	0.46	0.46	0.00	T.	1.12	0.00	0.23	0.06	0.31	2.49	1.56	7.56
1887–88	0.88	0.08	[0.50]	1.45	0.52	1.03	1.93	0.00	0.10	0.00	2.10	0.40	8.99
1888–89	0.63	1.73	1.76	2.84	1.62	1.33	2.15	0.25	0.00	T.	1.83	0.87	15.01
1889–90	2.05	0.60	0.40	2.30	2.11	1.66	1.03	1.31	0.00	0.00	2.25	3.41	17.12
1890–91	0.89	1.22	2.12	2.63	0.75	5.25	0.47	0.00	0.77	0.00	0.57	1.00	15.67
1891–92	0.75	0.00	0.00	1.44	1.80	3.51	1.22	1.03	0.08	0.00	1.30	1.90	13.03
1892–93	0.00	0.65	0.34	0.22	0.50	0.55	2.96	0.00	0.67	0.00	0.80	3.78	10.47
1893–94	2.56	0.00	0.34	0.37	0.63	1.37	1.14	0.11	0.31	0.00	0.81	2.06	9.70
1894–95	0.09	1.05	0.00	2.58	2.16	0.45	0.18	0.00	0.04	0.05	0.32	2.39	9.31
1895–96	1.94	3.01	3.42	0.45	0.43	0.04	0.50	T.	0.00	T.	3.78	0.88	14.45
Mean	0.96	0.85	0.82	1.62	1.15	1.72	1.26	0.26	0.25	0.15	1.66	2.33	13.03

Record of precipitation at Benson, Cochise County.

[Latitude 32° 00′, longitude 110° 22′; elevation, 3,580 feet. Authority, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880–81	[0.71]	0.00	0.00	[1.50]	0.00	0.00	0.75	0.00	0.00	0.02	2.17	4.33	9.48
1881–82	0.99	0.34	0.00	0.00	0.40	1.20	0.00	0.00	0.00	0.86	2.00	3.58	9.37
1882–83	0.65	0.00	0.80	0.15	0.65	0.63	2.08	0.00	0.42	0.16	2.97	2.78	11.29
1883–84	0.10	0.21	0.07	0.50	0.20	0.63	1.20	T.	0.00	0.00	0.70	0.27	3.88
1884–85	0.30	2.89	T.	2.50	0.05	0.95	0.07	0.00	0.00	0.75	0.58	1.44	9.53
1885–86	0.14	0.00	0.09	0.17	0.79	0.67	0.08	0.00	0.00	0.00	1.44	2.68	6.06
1886–87	0.17	0.25	0.00	0.19	0.00	0.34	0.00	T.	0.08	0.00	1.49	2.39	4.91
1887–88	2.92	0.45	0.37	0.15	0.04	0.00	0.30	0.00	0.37	0.00	2.44	1.66	8.70
1888–89	0.05	0.84	1.11	1.03	0.93	0.07	0.63	0.00	0.00	0.63	2.16	0.94	8.39
1889–90	1.04	0.05	0.00	1.33	1.94	0.00	0.00	0.23	0.00	0.52	[2.50]	4.81	12.42
1890–91	1.44	0.41	0.50	1.48	0.38	1.31	0.15	0.00	[0.00]	[0.25]	1.19	1.81	8.92
1891–92	0.34	0.00	0.00	0.38	0.40	1.30	0.40	0.42	0.00	0.00	0.00	0.07	3.31
1892–93	0.03	0.00	0.00	[0.63]	0.00	0.00	[0.92]	0.00	0.76	0.00	2.88	3.03	8.25
1893–94	0.12	0.00	0.00	0.00	T.	1.50	0.40	0.00	0.00	0.10	1.65	2.03	5.80
1894–95	0.95	0.00	0,00	0.74	0.00	0.00	[0.47]	0.00	1.00	0.00	0.13	1.20	4.49
1895–96	1.40	0.00	0.00	0.00	0.10	0.00	0.12	0.00	0.00	0.00	0.00	0.60	4.77
Mean	0.71	0.34	0.18	0.63	0.36	0.54	0.47	0.04	0.16	0.21	1.68	2.10	7.42

Record of precipitation at Tucson, Pima County.

[Latitude 32° 14′, longitude 110° 54′; elevation, 2,404 feet. Authority, Pacific Railway System and E. L. Wetmore.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76	------	------	0.18	0.82	0.37	0.25	1.22	0.00	0.00	0.29	3.71	4.19	---------
1876-77	2.28	0.96	0.75	0.00	0.19	2.53	0.20	0.57	0.41	0.00	3.04	0.02	10.95
1877-78	2.44	0.46	0.00	2.91	0.22	1.00	1.77	0.52	0.00	0.65	5.72	4.71	20.40
1878-79	0.08	0.00	1.31	0.68	2.02	0.94	0.83	0.02	0.00	0.01	0.84	1.76	8.49
1879-80	0.74	0.94	0.60	3.31	0.56	0.15	0.41	0.04	0.00	T.	1.62	1.28	9.65
1880-81	1.89	0.09	0.00	0.57	0.05	0.25	1.17	0.62	0.04	0.00	5.69	3.92	14.29
1881-82	2.37	0.62	0.00	0.19	1.75	1.64	0.72	0.05	0.01	0.99	2.63	6.32	17.29
1882-83	0.32	0.00	1.12	0.04	1.27	0.51	1.14	T.	0.35	0.08	2.20	1.40	8.43
1883-84	0.10	0.65	0.02	0.06	0.83	2.59	1.91	0.17	0.23	0.23	0.32	1.15	8.26
1884-85	0.30	2.24	0.34	4.72	0.00	0.42	0.40	0.00	0.00	0.13	1.00	1.76	11.31
1885-86	0.12	0.00	0.42	1.01	1.61	0.36	0.87	0.06	0.00	0.00	1.06	2.47	7.98
1886-87	[1.00]	0.31	0.45	0.40	0.00	0.85	0.00	0.38	0.32	0.26	5.08	1.25	10.30
1887-88	2.08	1.72	0.74	0.27	0.73	0.57	1.03	T.	0.32	0.55	1.58	0.92	10.51
1888-89	0.10	0.78	2.06	1.96	1.74	1.06	1.98	0.18	T.	0.30	5.66	2.06	17.88
1889-90	3.12	0.36	0.32	1.59	1.27	0.76	0.29	0.10	0.00	0.00	2.37	5.13	15.31
1890-91	1.44	0.65	0.83	1.32	0.12	2.08	0.17	0.00	0.18	0.22	0.70	2.26	9.97
1891-92	0.65	0.00	0.00	0.23	1.66	2.54	1.01	0.26	0.36	0.21	2.19	1.84	10.95
1892-93	0.61	0.32	0.00	0.25	0.27	0.88	1.16	T.	1.09	0.00	2.44	5.65	12.67
1893-94	0.96	T.	0.40	0.41	0.11	1.04	1.17	T.	0.05	T.	1.60	1.01	6.75
1894-95	0.12	0.31	0.00	1.88	0.56	T.	0.00	T.	0.09	0.02	0.11	5.35	8.44
1895-96	0.75	0.68	4.30	0.08	0.53	0.10	0.27	0.12	T.	0.19	3.45	1.25	11.72
Mean	1.07	0.55	0.66	1.08	0.76	0.98	0.84	0.15	0.16	0.20	2.52	2.65	11.62

Record of precipitation at Casa Grande, Pinal County.

[Latitude 32° 54′, longitude 111° 40′; elevation, 1,398 feet. Authority, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880-81	[0.45]	0.05	0.00	[1.00]	0.00	0.00	[1.00]	0.73	0.00	0.00	0.00	T.	3.23
1881-82	0.00	0.00	0.00	0.00	[2.00]	[0.80]	0.00	0.00	0.00	[0.10]	0.00	0.00	2.90
1882-83	0.00	0.00	[0.35]	0.00	0.00	0.00	0.00	0.00	0.24	0.00	[1.00]	0.81	2.40
1883-84	0.00	0.10	0.00	0.86	0.75	[1.00]	1.08	0.00	0.00	0.00	0.00	2.37	6.16
1884-85	0.00	1.31	0.00	3.20	0.00	0.30	0.10	0.00	0.00	0.00	0.75	0.64	6.30
1885-86	0.00	0.00	0.23	0.00	0.90	[1.25]	0.74	0.09	0.00	0.00	0.33	1.46	5.00
1886-87	0.00	0.00	0.35	0.00	0.00	0.40	0.00	0.30	0.20	0.40	1.07	0.97	3.69
1887-88	1.99	0.95	1.28	0.15	0.61	0.00	0.45	0.00	[0.10]	0.00	0.28	0.00	5.81
1888-89	0.41	[1.00]	0.70	0.75	[1.00]	0.00	0.50	0.10	0.00	0.00	0.00	0.00	4.46
1889-90	0.50	0.80	0.10	1.25	0.30	0.61	0.41	0.38	0.00	0.00	1.38	3.41	9.14
1890-91	0.96	0.38	2.00	0.87	0.65	1.90	0.00	0.00	0.00	0.00	0.90	0.00	7.66
1891-92	0.00	0.00	0.00	0.17	3.25	2.35	0.65	0.00	0.34	0.00	0.23	0.64	7.63
1892-93	0.00	0.15	0.00	1.14	0.06	0.00	1.87	0.00	0.07	0.00	1.72	0.95	5.96
1893-94	0.00	0.00	0.00	0.25	0.00	0.10	0.62	0.00	0.07	0.00	0.67	0.81	2.52
1894-95	0.89	0.13	0.00	2.53	0.45	0.00	0.00	0.00	0.00	0.00	0.35	1.30	5.65
1895-96	2.00	1.60	0.60	------	0.65	0.00	0.10	0.00	0.00	0.00	------	0.88	---------
Mean	0.45	0.40	0.35	0.81	0.66	0.54	0.47	0.10	0.06	0.03	0.58	0.89	5.34

Record of precipitation at Maricopa, Pinal County.

[Latitude 33° 05′, longitude 112° 00′; elevation, 1,190 feet. Authority, Pacific Railway System and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76	------	------	0.00	0.00	0.72	0.27	0.39	0.00	0.00	0.45	0.44	1.09	---------
1876-77	0.00	0.10	0.41	0.00	0.08	1.57	0.30	0.03	0.41	0.00	1.26	0.00	4.16
1877-78	1.07	0.00	0.01	1.54	0.00	1.01	------	------	------	------	------	------	---------
1878-79	------	------	------	------	------	------	------	------	------	0.00	0.10	1.81	---------
1879-80	0.38	0.04	0.85	0.80	1.45	0.16	0.00	0.75	0.00	0.00	0.00	0.00	4.43
1880-81	0.50	0.00	0.00	0.50	0.00	0.00	0.88	0.00	0.00	0.00	0.00	1.47	3.35
1881-82	0.50	0.00	0.00	0.00	T.	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.88
1882-83	0.00	0.00	0.00	0.00	1.34	0.00	0.00	0.00	0.00	0.00	0.50	3.57	5.41
1883-84	0.30	0.00	0.00	1.96	0.38	0.74	2.83	0.51	0.01	0.32	0.53	0.86	8.44
1884-85	1.10	1.51	0.20	2.97	0.00	0.45	0.15	0.00	0.18	0.04	0.48	0.92	8.00
1885-86	T.	0.00	0.56	0.19	1.32	1.65	1.71	0.06	0.00	0.00	0.16	0.08	5.73
1886-87	0.06	0.76	0.21	0.11	0.00	0.17	T.	0.51	0.31	0.03	0.43	0.50	3.09
1887-88	1.00	0.28	1.13	0.00	0.00	0.12	0.48	0.00	0.00	0.00	0.80	0.22	4.03
1888-89	0.35	0.52	0.75	0.70	0.85	0.15	1.19	0.00	0.00	0.00	0.55	0.90	5.96
1889-90	0.90	1.20	0.83	3.00	0.00	0.22	1.02	0.00	0.00	0.00	0.10	4.29	11.56
1890-91	0.15	0.07	0.31	2.47	0.02	2.33	0.00	0.01	0.00	0.00	0.13	0.39	5.88
1891-92	0.13	0.00	0.00	0.00	1.55	2.44	0.50	0.40	0.14	0.00	0.62	0.25	6.03
1892-93	0.15	0.00	0.00	0.00	1.26	0.00	1.14	0.00	0.64	0.00	0.68	0.50	4.37
1893-94	2.08	0.00	0.30	0.00	0.32	0.12	0.50	0.00	0.00	0.00	0.38	1.96	5.66
1894-95	0.35	0.50	0.00	2.44	0.61	0.00	0.00	0.00	0.00	0.00	0.93	0.85	5.68
1895-96	1.10	1.10	1.48	0.00	0.68	0.00	0.22	0.00	0.00	0.03	1.18	0.27	6.06
Mean	0.53	1.01	0.35	0.83	0.52	0.57	0.60	0.12	0.81	0.04	0.46	1.01	6.85

Record of precipitation at Texas Hill, Yuma County.

[Latitude 32° 44′, longitude 113° 38′; elevation, 355 feet. Authority, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Total.
1879-80	0.05	0.55	0.43	0.47	0.23	0.00	0.00	0.06	0.00	0.00	0.00	0.00	1.79
1880-81	0.35	0.00	0.00	0.34	0.00	0.00	0.24	0.56	0.00	0.00	0.03	0.24	1.76
1881-82	0.12	2.50	0.00	0.18	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.53	5.20
1882-83	[0.00]	0.05	0.12	0.00	0.19	0.14	0.20	0.03	0.00	0.00	0.68	0.70	2.11
1883-84	0.00	0.09	[0.00]	1.05	0.22	1.21	1.75	0.28	0.28	0.00	0.00	0.00	4.88
1884-85	0.02	0.00	0.00	1.26	0.00	0.04	0.02	0.00	0.00	0.00	0.00	2.25	3.59
1885-86	0.00	0.00	0.32	0.00	0.93	1.15	0.00	0.20	0.00	0.00	T.	0.95	3.55
1886-87	0.00	1.50	0.00	0.00	0.00	0.01	0.00	T.	0.00	0.00	T.	T.	1.51
1887-88	2.89	0.00	1.40	0.05	0.25	0.00	0.63	0.00	0.00	0.00	0.08	0.00	5.30
1888-89	[0.30]	1.94	[0.50]	1.29	2.65	0.00	0.12	0.00	0.00	0.00	T.	0.00	6.80
1889-90	0.00	0.10	0.05	0.62	0.00	0.40	0.00	0.00	0.00	0.00	0.10	[0.50]	1.77
1890-91	0.10	0.03	0.10	1.28	0.00	2.50	0.00	0.00	0.00	0.00	0.11	0.65	4.77
1891-92	0.20	0.00	0.00	[0.05]	1.64	------	------	------	0.00	0.00	0.00	0.00	---------
1892-93	0.00	0.00	0.00	0.00	0.00	0.00	[1.50]	0.00	0.00	0.00	0.40	0.00	1.90
1893-94	0.00	0.00	0.00	0.00	------	------	------	------	------	------	------	------	---------
1894-95	------	------	------	------	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---------
1895-96	0.00	0.00	0.10	0.00	0.00	0.00	0.75	0.00	0.00	0.00	1.15	1.20	3.20
Mean	0.25	0.42	0.18	0.41	0.50	0.36	0.35	0.08	0.02	0.00	0.16	0.43	3.16

Record of precipitation at Yuma, Yuma County.

[Latitude 32° 44′, longitude 114° 36′; elevation, 141 feet. Authority, Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1875-76	[0.17]	T.	0.00	0.00	0.44	0.46	0.04	0.00	0.00	0.00	0.00	0.00	1.11
1876-77	0.00	0.00	0.00	0.00	0.09	1.72	0.00	0.00	0.06	0.00	0.50	0.06	2.43
1877-78	T.	0.00	0.00	1.23	0.00	0.06	0.13	0.02	0.00	0.00	0.55	1.59	3.58
1878-79	0.37	0.00	0.02	0.14	0.59	1.21	0.48	0.15	0.00	0.00	0.00	0.00	2.96
1879-80	0.11	0.33	0.15	0.27	T.	T.	0.00	T.	0.00	0.00	T.	T.	0.86
1880-81	T.	T.	0.00	0.74	0.00	0.00	T.	0.55	0.00	T.	0.20	0.08	1.57
1881-82	0.05	T.	0.00	0.10	1.35	0.01	0.00	0.00	0.00	0.05	0.20	0.03	1.79
1882-83	0.04	0.01	0.09	0.00	0.96	0.68	T.	T.	0.00	0.00	0.31	0.22	2.31
1883-84	0.13	0.05	0.00	[1.61]	T.	1.58	1.48	0.07	0.44	T.	0.01	0.32	5.69
1884-85	T.	T.	T.	1.96	T.	0.02	T.	0.07	T.	0.00	0.05	0.86	2.96
1885-86	0.00	0.00	1.71	0.01	1.06	0.08	0.33	0.31	0.00	0.00	T.	2.23	5.73
1886-87	0.00	1.11	0.23	0.00	0.00	T.	0.00	0.20	T.	0.01	T.	T.	1.55
1887-88	1.09	0.02	2.43	0.15	0.18	0.05	0.05	T.	0.00	0.00	0.04	T.	4.01
1888-89	0.01	0.99	0.68	0.95	1.12	0.06	0.24	0.00	0.00	T.	T.	0.25	4.30
1889-90	0.00	0.59	T.	2.43	T.	0.86	T.	0.37	0.43	0.00	0.00	0.67	5.35
1890-91	0.64	------	------	------	0.00	2.53	T.	0.00	T.	0.00	0.04	0.05	--------
1891-92	T.	0.00	0.00	0.05	1.85	0.87	0.52	T.	0.05	0.00	0.00	0.02	3.36
1892-93	0.04	0.00	0.00	T.	T.	[0.57]	1.53	0.00	0.31	0.00	0.40	0.42	3.27
1893-94	0.30	0.00	0.30	0.11	0.00	T.	0.74	0.00	T.	0.00	0.36	0.10	1.91
1894-95	0.51	0.84	0.00	0.40	0.77	------	------	------	------	------	------	------	--------
Mean	0.17	0.21	0.30	0.53	0.42	0.57	0.29	0.09	0.07	------	0.14	0.36	3.15

Miscellaneous rainfall observations in Arizona, 1896.

Stations.	Elevation.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Buttes	1,600	0.66	0.16	0.77	0.12	0.00	0.00	3.10	0.90	1.69	1.27	0.67	1.09	10.43
Pinal	2,550	------	------	------	0.20	0.00	0.00	2.13	1.19	0.90	3.28	1.22	1.27	--------
Whitlows	2,050	------	------	------	------	0.00	0.06	2.67	1.58	1.68	3.16	1.21	0.91	--------
Silver King	3,650	2.25	0.35	0.00	0.10	0.00	0.00	4.74	3.03	2.73	3.66	3.40	0.90	21.16

IRRIGATED VINEYARD NEAR PHŒNIX, ARIZONA.

WIND.

The amount and violence of the wind movement is of considerable importance in a climate such as that of Arizona, on account of its effect not only upon the vegetation but also to a certain degree upon the comfort of the inhabitants. A considerable amount of wind is not only injurious to fruit trees, but, by continually keeping the dust in motion in such an excessively dry country, renders outdoor life extremely annoying to persons who from lung or throat troubles seek refuge in an arid climate. Fortunately, as indicated by the records and shown by common experience, the wind movement in the Salt and Gila valleys is relatively small, so that the orchards are rarely injured and the amount of dust in the air is not often noticeable. With every advantage of this kind there may be a small loss, and in this case the principal drawback is in the fact that windmills can not be used to as great advantage in pumping water as out upon the Great Plains, where the wind has a sweep found nowhere else and prevails throughout the year.

Wind movements have been carefully recorded at a number of places within the Territory, the principal of these within or near the Gila Basin being Fort Apache, Fort Grant, Phœnix, Prescott, and Yuma. The record at Phœnix from 1879 to 1881 gives an average hourly wind movement of only 2.4 miles. This small amount is accounted for by the fact that the anemometer was exposed only 19 feet above the ground. As stated by the Chief of the Weather Bureau, in August, 1895, when the station was reestablished, the anemometer was placed 57 feet above the ground, giving considerable higher velocities, the monthly averages being about 5 miles per hour, or more than twice those previously obtained. The averages for Fort Apache were 6.4 miles per hour, for Fort Grant 6.8, for Prescott 6.9, and for Yuma 6.1, all of these being low in consideration of windmill efficiency.

The distribution of wind through the day is very clearly marked. Beginning at about 10 o'clock in the morning, the wind usually increases from about 3 miles per hour up to from 8 to 12 miles per hour at 3 o'clock in the afternoon. At sundown it decreases, dropping off rapidly until midnight, and slowly decreasing in force until about the middle of the forenoon of the next day. Thus, as a rule, nearly all of the effective wind movement occurs within six hours in the afternoon, or from about 1 or 2 o'clock until about sundown. The distribution of wind through the year is comparatively uniform, the greatest amount being in the spring months, the strength decreasing notably during September and October. By erecting tall windmills in well-exposed localities it may be practicable to utilize these to a notable extent in pumping water for irrigation, but to attain success these must be proportioned to the prevailing strength of the wind and to the work to be done. Even if these operate during only one-fourth of the day, it may be possible, by providing suitable small ponds or earthen tanks, to hold sufficient water for the irrigation of gardens and a small area of forage plants.

PRODUCTS.

It need hardly be stated that on the deep alluvial soil of the valleys in such a climate as that described the growth of nearly all kinds of vegetation is luxuriant if only sufficient water be applied. All warm temperate and many semitropic products flourish here, and most of them produce in an abundance indicated by the favorable climate. The principal crops now grown are alfalfa, wheat, and barley, with more or less of peaches, grapes, apricots, oranges, and other fruits, and a variety of vegetables.

Gila Valley aspires to competition with California in the citrus fruit market, and a number of thriving orange groves indicate that in certain localities the climate and soil are favorable to success. Although there have been many failures, mainly from frost, it should be remembered that this has been the case in every citrus region at first, and that even in California only occasional spots and strips are sufficiently free from frost and other foes of the citrus family to be profitably devoted to this branch of fruit culture. Past experience seems to indicate that, as in California, there are exceptional thermal belts sufficiently exempt from frost to permit profitable growth of oranges and lemons, but such belts can be located only by observation and experience, and their discovery is often preceded by failures due to ignorance or disregard of the true conditions.

There are two respects in which Arizona seems to enjoy a decided advantage over California in the production of citrus fruits: First, the extreme heat and aridity of the climate are claimed to be unfavorable to the development and spread of such enemies of citrus growth as the scale bug (*Aspidiotus perniciosus*) in its several varieties; second, oranges, as well as some deciduous fruits, mature from two to four weeks earlier than in most parts of California, and they thus secure the advantage of an early market, which is always the best. The lemons produced in this valley are beautiful in appearance, of large size, and of excellent flavor. It would appear that this valley is under a disadvantage owing to the inconvenience or expense of curing lemons, which process requires the steady maintenance of a low temperature. The great distance from any sufficiently cool climate and the expense of maintaining local refrigeration seem to stand in the way. Claims are made that the Arizona product does not require curing as in other lemon-growing regions, but this claim seems not yet to be well established. Undoubtedly, however, though lemon culture will be somewhat more restricted than orange culture, it has come to stay. The actual location and development of favorable localities along the lines mentioned will be slow, but enough is known to guarantee the fact

FIG TREE NEAR PHŒNIX, ARIZONA.

that if citrus culture continues as profitable as it has been in the past, Arizona will some day be one of the important competitors for a share of the citrus market.

This valley appears to be preeminently the home of the grape. Table grapes of good quality and wine grapes yielding a very superior product may be grown here in abundance, as already proved by experience. Undoubtedly, also, the raisin industry will some day be important, and the hot, dry summers are favorable to the production of a superior article. In one respect, however, this valley is under a disadvantage as compared with southern California, in that it is more likely to receive sudden showers of rain during the curing season.

Claims are also made of the superiority of this region for such products as figs, prunes, almonds, pomegranates, olives, and even dates. Undoubtedly figs and prunes can be successfully grown, and the experience obtained with almonds both in this and other localities seems to justify the claims made regarding this product, but most of the other fruits mentioned are still in the experimental stages. It is doubtful if dates can be profitably grown except in some favored and well-sheltered localities. Apples appear not to do well in a climate like that of Arizona. Even those varieties which can be abundantly grown are inferior in quality and quickly decay. This fruit is better adapted to a colder climate. The same appears to be true in a less degree of pears. Most small fruits yield abundantly, and so far have been very profitable.

The quantities of fruits and vegetables which have been exported from Arizona are inconsiderable. On the contrary, large quantities of some kinds are annually imported for consumption in the industries of mining and grazing. These two interests are the main sources of exportable products, and agriculture and horticulture, so far as developed, are devoted chiefly to satisfying their wants. Alfalfa may be taken as the staple agricultural product, and is largely utilized in the fattening of cattle grown on the ranges of the adjacent mountains and foothills. Large areas of this productive forage plant are used as pasture, while others are utilized for maturing hay. Barley is largely used as hay, and also furnishes the bulk of the grain fed to live stock in the valley.

METHODS OF APPLYING WATER.

Alfalfa and the grains being the principal crops of this region, it may readily be inferred that the usual method of applying water in irrigation is by flooding the ground, since these products lend themselves to this method most readily. This system, as is well known, is also susceptible of great wastefulness in its application, especially in an ultra-arid climate, since it wets the whole surface of the ground and gives full scope to evaporation, and is often followed by baking, which favors the rise of underground waters to the surface to evaporate.

In the irrigation of fruit trees and vines the furrow method is used, which, when properly employed, is an excellent method. Pl. VII shows the ground properly prepared for the furrow method of irrigation. The water is turned into each furrow at the upper edge of the field in just sufficient quantity to run freely down the furrow without erosion, and soaks gradually away downward and sidewise. As soon as it reaches the lower end of the furrow it is shut off at the upper end; thus only a small percentage of the surface of the ground is wet, and the water reaches the roots of the trees at some distance below the surface. A light cultivator should follow irrigation, filling the furrows with loose earth and leaving the surface of the ground level

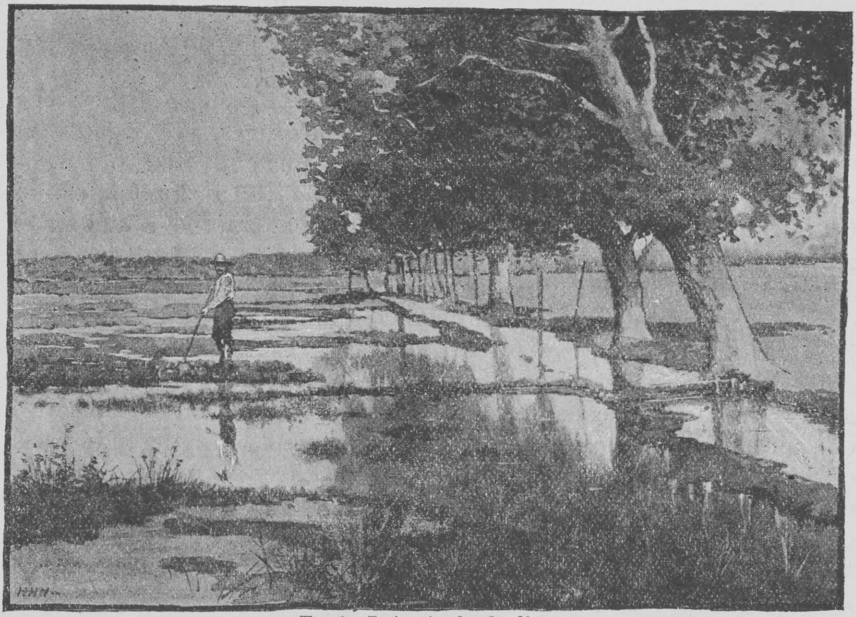


FIG. 2.—Irrigation by flooding

and dry, so that the minimum of evaporation takes place and no saturated surface is exposed to bake in the hot sun. Unfortunately, however, the predominance of the flooding system seems to influence irrigation by means of furrows, and the water is often so lavishly and carelessly applied that the ground is almost flooded, and the water stands in pools and furrows until the field becomes an absolute bog, a condition which is not only most wasteful of water, but actually injurious to the irrigated corps, by shutting off the ventilation of the roots. It also interferes with cultivation, causes the ground to bake, and allows the weeds to start. This is, however, by no means the universal practice, and many of the irrigators are approaching more and more nearly to ideal methods of irrigating. The Arizona Improve-

PALM AVENUE NEAR PHŒNIX, ARIZONA.

ment Company is setting an excellent example in this respect, as are also some of the individual irrigators, and the neat appearance of the orchards might profitably be emulated by many a city park.

WATER SUPPLY.

In comparison with the size of the Territory and the importance of its water resources, the hydrographic data are very meager. Some measurements of stream flow were made in 1889 and 1890 by the United States Irrigation Survey at a point about 14 miles above Florence, on the Gila River, known as The Buttes. Gaugings at this point were resumed in December, 1895, and are still being carried on, the

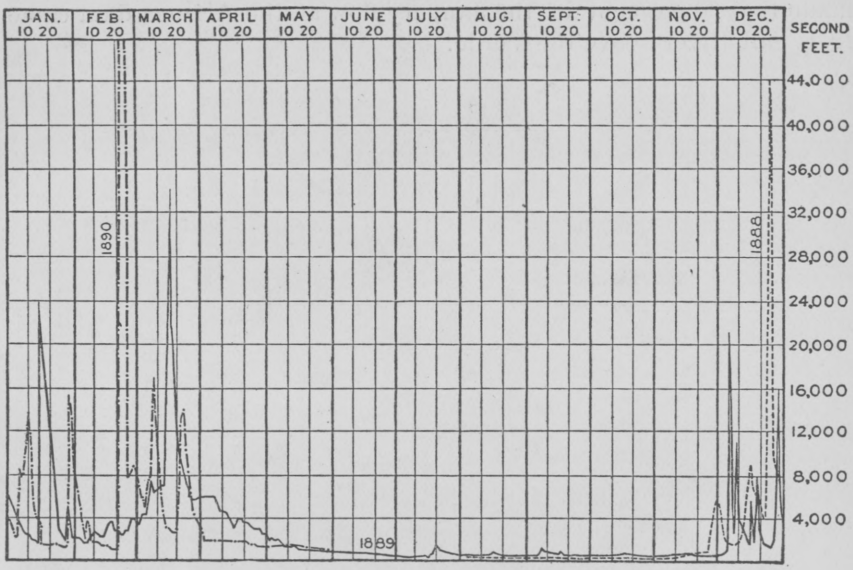


FIG. 3.—Daily discharge of Salt River at Arizona dam, 1888-1891.

results being used also to estimate the discharge from gauge readings and soundings taken during the fall of 1895 by private parties. Measurements have also been made by the United States Government of the discharge of Queen Creek, a small intermittent stream tributary to the Gila River.

Approximate estimates of the discharge of Salt River were made by Mr. Samuel Davidson from data obtained by the Arizona Cana-Company at its dam a short distance below the junction of the Salt and Verde rivers.

Measurements of discharge have been more recently made on Salt and Verde rivers by the Hudson Reservoir and Canal Company. Surface velocities were measured by means of floats, and eight-tenths of the result thus obtained was assumed as the mean velocity, and multiplied into the cross section determined by sounding, to obtain the discharge, the sum of the discharges of both being adopted as the flow of Salt River below the junction. The measurements were begun on February 4, 1895, and were continued through the year without interruption except on the four days from October 4 to 7, inclusive, on Verde River, which was during that time inaccessible. An estimate for those four days has been made from the highest watermark found at the gauge and from such other data as were available. Also, for the month of January, one of the most important flood months of the year, estimates have been prepared from the daily record taken at the Arizona dam, about a mile below the junction of the two rivers. It appears from all available data that Salt River furnishes a considerably larger proportion of water than Verde River, and the assumption has been made that 60 per cent of the January flow at the Arizona dam came from Salt River above the Verde.

VIEW ON BARTLETT RANCH, NEAR PHŒNIX, ARIZONA.

The results of the computed discharges for each locality are given in the following tables:

Estimated monthly discharge of Salt River at Arizona dam, Arizona.

[Drainage area, 12,260 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1888.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
August	----------	----------	350	21,525	0.03	0.028
September	----------	----------	350	20,825	0.03	0.028
October	350	300	331	20,356	0.03	0.027
November	5,760	425	842	50,099	0.08	0.068
December	43,489	1,665	6,698	411,927	0.63	0.545
1889.						
January	24,953	1,665	5,947	365,740	0.56	0.48
February	3,940	1,534	2,605	144,577	0.22	0.22
March	33,794	3,563	8,745	537,817	0.82	0.71
April	5,559	2,496	3,975	236,512	0.36	0.32
May	1,784	622	1,039	63,898	0.10	0.08
June	615	356	470	27,965	0.04	0.04
July	1,311	334	495	30,522	0.05	0.04
August	755	389	417	25,645	0.04	0.03
September	1,172	389	521	31,000	0.05	0.04
October	704	319	440	27,060	0.04	0.04
November	629	532	576	34,272	0.05	0.05
December	25,371	557	5,686	349,689	0.53	0.46
1890.						
January	15,750	1,376	4,982	306,393	0.47	0.40
February	143,288	1,045	10,097	560,383	0.86	0.82
March	17,228	2,566	6,421	394,891	0.60	0.52
April	2,077	1,369	1,840	109,480	0.17	0.15
May	1,369	630	914	56,211	0.09	0.08
June	672	397	511	30,404	0.05	0.04
July	872	397	524	32,226	0.05	0.04
August	7,734	1,114	3,885	238,927	0.37	0.32
September	3,685	725	2,339	139,170	0.21	0.19
October	7,465	753	2,768	160,232	0.25	0.23
November	30,504	766	4,717	280,661	0.43	0.38
December	30,366	1,110	6,259	384,928	0.59	0.51
1891.						
January	17,127	1,060	3,416	210,084	0.32	0.28
February	300,000	825	39,201	2,175,655	3.32	3.10

Estimated discharge of Verde River above Salt River, Arizona.

[Drainage area, 6,000 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1895.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
January	33,000	527	4,037	248,225	0.77	0.67
February	5,800	583	1,688	93,747	0.29	0.28
March	8,400	1,887	3,720	228,734	0.71	0.62
April	2,800	280	750	44,628	0.14	0.13
May	429	127	258	15,864	0.04	0.04
June	180	129	153	9,104	0.03	0.03
July	275	116	145	8,916	0.02	0.02
August	1,426	185	359	22,074	0.07	0.06
September	348	141	176	10,473	0.03	0.03
October	3,912	197	475	29,207	0.09	0.08
November	1,800	241	463	27,550	0.09	0.08
December	881	345	391	24,042	0.08	0.07
Total, year	33,000	116	1,051	762,564	2.36	0.18
1896.						
January	354	314	324	19,923	0.06	0.05
February	352	278	154	8,852	0.03	0.03
March	338	258	276	16,971	0.06	0.05
April	237	206	220	13,090	0.04	0.04
May	206	138	172	10,576	0.03	0.03
June	137	101	117	6,962	0.02	0.02
July	3,380	98	864	53,127	0.16	0.14

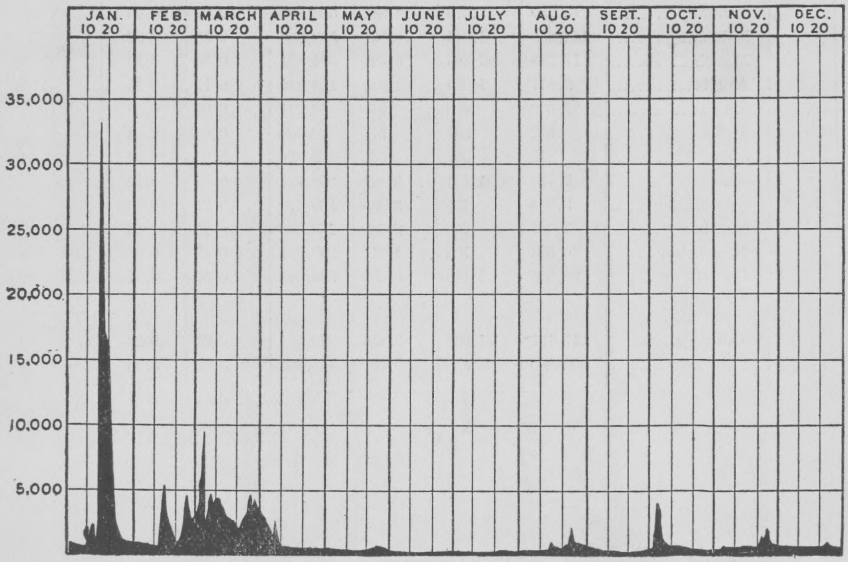


FIG. 4.—Daily discharge of Rio Verde above Salt River, 1895.

DRYING APRICOTS.

Estimated discharge of Salt River above mouth of Verde River, Arizona.

[Drainage area, 6,260 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1895.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
January	49,796	791	5,733	352,508	1.06	0.92
February	3,892	914	1,445	80,251	0.24	0.23
March	3,340	1,319	1,829	112,461	0.33	0.29
April	2,939	1,044	1,860	110,678	0.33	0.30
May	990	505	708	43,533	0.13	0.11
June	500	206	325	19,339	0.06	0.05
July	896	145	204	12,543	0.03	0.03
August	1,516	226	584	35,909	0.10	0.09
September	684	201	329	19,577	0.06	0.05
October	13,205	390	1,624	99,856	0.30	0.26
November	9,620	380	1,376	81,878	0.25	0.22
December	2,055	513	888	54,601	0.16	0.14
Total, year	49,796	145	1,408	1,023,134	3.05	0.22
1896.						
January	613	400	470	28,900	0.08	0.07
February	612	414	476	27,380	0.09	0.08
March	3,020	457	1,185	72,863	0.22	0.19
April	1,660	605	959	57,061	0.17	0.15
May	621	335	446	27,424	0.08	0.07
June	332	158	224	13,328	0.04	0.04
July	4,377	151	639	39,292	0.12	0.10

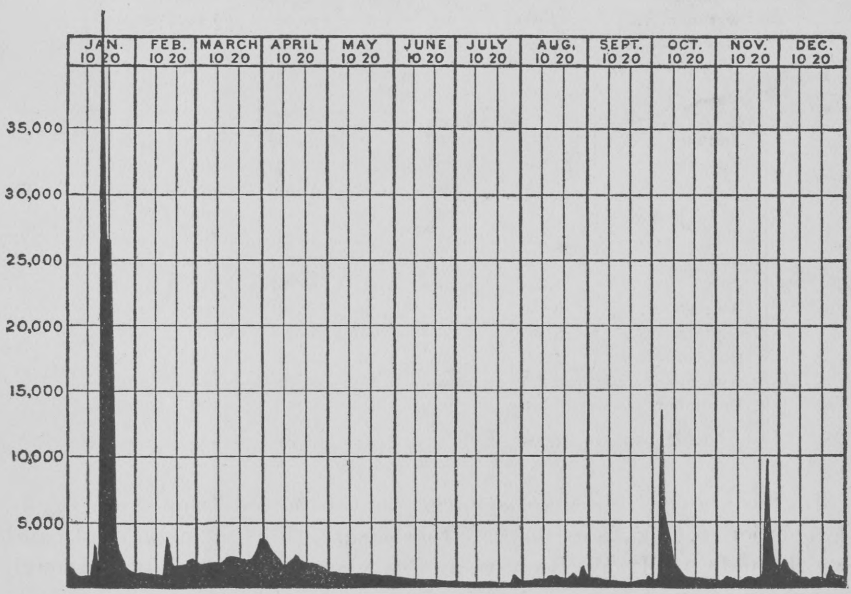


FIG. 5.—Daily discharge of Salt River above Verde, 1895.

The following table shows the discharge of Gila River for the season of 1889–90, measured by the irrigation survey, and the results from measurements still in progress for the season just closed:

Estimated discharge of Gila River at The Buttes, Arizona.

[Drainage area, 13,750 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1889.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
September	210	90	128	7,616	0.010	0.009
October	210	140	157	9,655	0.013	0.011
November	250	156	212	12,614	0.017	0.015
December	890	124	275	16,909	0.023	0.020
1890.						
January	2,100	310	680	41,812	0.056	0.049
February	1,514	405	578	32,100	0.043	0.042
March	710	300	387	23,795	0.032	0.028
April	333	158	238	14,161	0.019	0.017
May	150	35	87	5,350	0.007	0.006
June	35	27	28	1,666	0.002	0.002
July	3,112	11	130	7,995	0.010	0.009
August	6,330	1,115	3,137	192,888	0.263	0.228
Total, year				366,561		
1895.						
August	3,910	536	1,583	97,336	0.133	0.115
September	2,880	300	812	48,317	0.065	0.059
October	12,000	400	1,577	96,966	0.133	0.115
November	7,500	300	1,103	65,633	0.089	0.080
December	1,150	518	751	41,627	0.056	0.049
1896.						
January	560	250	396	24,349	0.032	0.028
February	340	175	209	12,022	0.016	0.015
March	356	153	242	14,880	0.021	0.018
April	340	68	180	10,710	0.014	0.013
May	68	12	32	1,968	0.002	0.002
June	32	1	5	298	0.0003	0.003
July	11,708	1	1,441	88,604	0.121	0.105
August	3,150	175	810	49,805	0.068	0.059
September	2,850	455	980	58,314	0.079	0.071
October	7,243	1,030	4,145	254,867	0.347	0.301
November	2,275	696	1,037	61,706	0.083	0.075
December	710	576	629	38,676	0.053	0.046
Total, 1896	11,708	1	842	616,201	0.839	0.062

In the above table the discharge for the period from August 1 to December 10, 1895, is estimated from observations of mean depth and width made by Mr. W. Richins, and can be considered only as a rough approximation.

IRRIGATION BY FURROW METHOD.

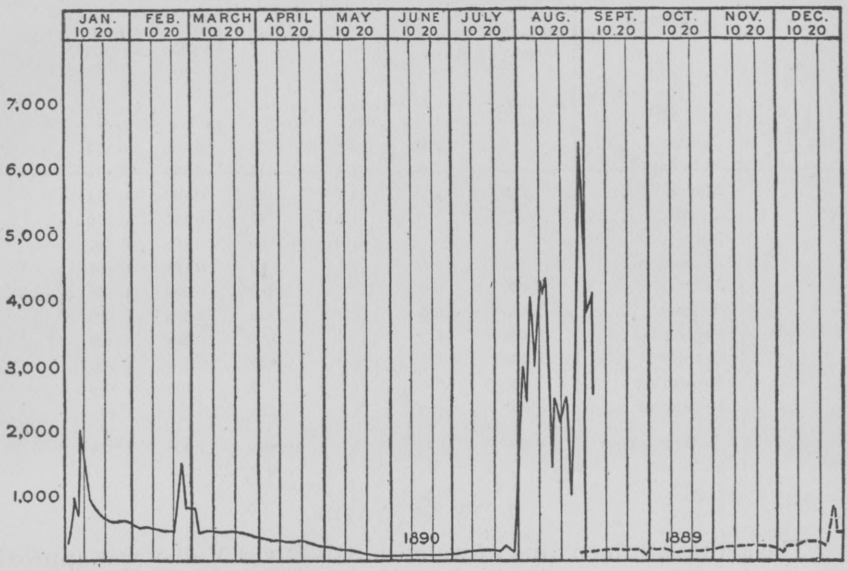


FIG. 6.—Daily discharge of Gila River at The Buttes, 1889-1890.

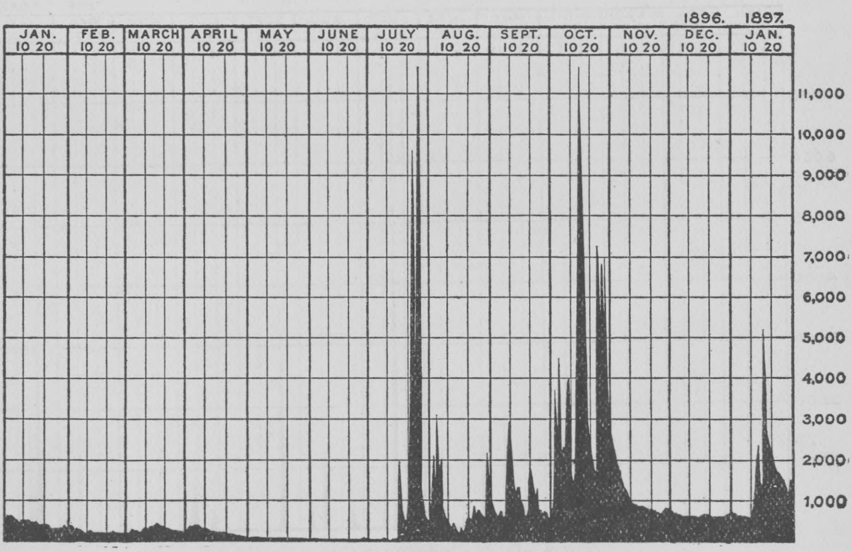


FIG. 7.—Daily discharge of Gila River at The Buttes, 1896.

Estimated monthly discharge of Queen Creek, Whitlows, Arizona.

[Drainage area, 143 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1896.	*Second-feet.*	*Second-feet.*	*Second-feet.*	*Acre-feet.*	*Inches.*	*Second-feet.*
January	2	2.0	2.0	123	0.016	0.014
February	2	2.0	2.0	115	0.015	0.014
March	2	2.0	2.0	123	0.016	0.014
April	2	1.0	1.5	87	0.011	0.010
May	1	1.0	1.0	61	0.008	0.007
June	1	1.0	1.0	60	0.008	0.007
July	9,000	0.0	121.6	7,480	0.980	0.850
August	1,433	0.6	13.1	805	0.106	0.092
September	3,428	0.5	17.1	1,016	0.134	0.120
October	1,188	0.5	13.3	820	0.108	0.093
November	80	0.6	1.3	80	0.010	0.009
December	207	0.6	2.0	120	0.016	0.014
Total, year	9.000	0.0	15.0	10,890	1.428	0.104

DUTY OF WATER.

The actual attained duty of water in Salt River Valley was approximately determined in the year 1895. According to figures furnished by the Arizona Improvement Company, about 60.000 acres were irrigated on the north side of Salt River in that year. Of this, about 34,000 acres, or more than one-half, was in alfalfa; over one-fourth was in grain, and the remaining portion, or about one-sixth, was chiefly in fruit and garden or was occupied by streets and lots of

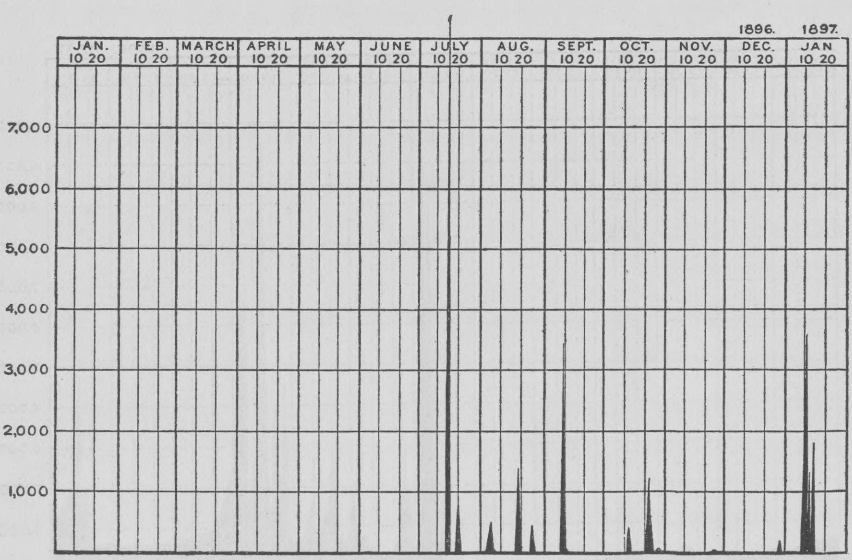


FIG. 8.—Daily discharge of Queen Creek.

FIELD PREPARED FOR IRRIGATION BY CHECKS.

the city of Phœnix. The total amount of water furnished for this area is stated to have been sufficient to cover the tract an average of 4.6 feet in depth. Mr. Samuel Davidson, who has given this matter careful study, states that the average amount of water used upon an acre of alfalfa is over 5 acre-feet; the amount for grain, which is of short season, is 1½ feet in depth, while fruits require somewhat more than grain but less than alfalfa, probably an average of 3 feet in depth. As much as 11 acre-feet of water has been applied in the growing of alfalfa in this valley.

The duty of water, as indicated by past experience and present usage, can be greatly increased. During the winter and early spring, owing to melting of snow in the mountains, the river furnishes a much larger volume of water than through the rest of the year. The abundance of water at this time, together with the knowledge that it will be scarce later in the season, induces the irrigators to apply it very lavishly while they have it, and in this manner a great excess reaches the land, standing in pools and furrows for a time, and large quantities evaporating. Other quantities seep away to reappear in the bed of the river, where, after the deduction of another large proportion by evaporation, they are rediverted for irrigation by the lower canals. The amount of this seepage was measured by Mr. Cyrus C. Babb in June, 1896, and the results showed in one case an increase of over 80 second-feet in a distance of 7 miles.

Another prolific source of waste of water is the large number of long laterals required to reach the scattered tracts of irrigated land. Less than half the irrigable land below the Arizona Canal is actually cultivated, and the utilization of some of the farms requires the construction of long laterals carrying small quantities of water, from which the loss by seepage and evaporation is great. Judge Kibbey, in the opinion hereafter quoted, states that the loss of water which is carried in small ditches for the purpose of watering stock is alone sufficient for the reclamation of 10,000 acres of land, if properly applied to irrigation.

If all the irrigable lands under the canals were brought under cultivation and water supplied to them in the most economical manner practicable, irrigation carried on both night and day, and each irrigator allowed the use of a measured quantity of water for a certain number of hours, unquestionably the duty of water could be greatly increased. Probably it would ultimately be found that 2 acre-feet per year would on the average be sufficient for an acre. The great aridity of this climate will always necessitate the use of larger quantities of water than would be necessary for the same results in a more humid climate.

As shown on page 46, the Florence Canal takes from Gila River nearly 10 acre-feet of water for each acre irrigated, but this can not be considered in any sense indicative of the duty of water, as the major portion is lost by seepage and evaporation.

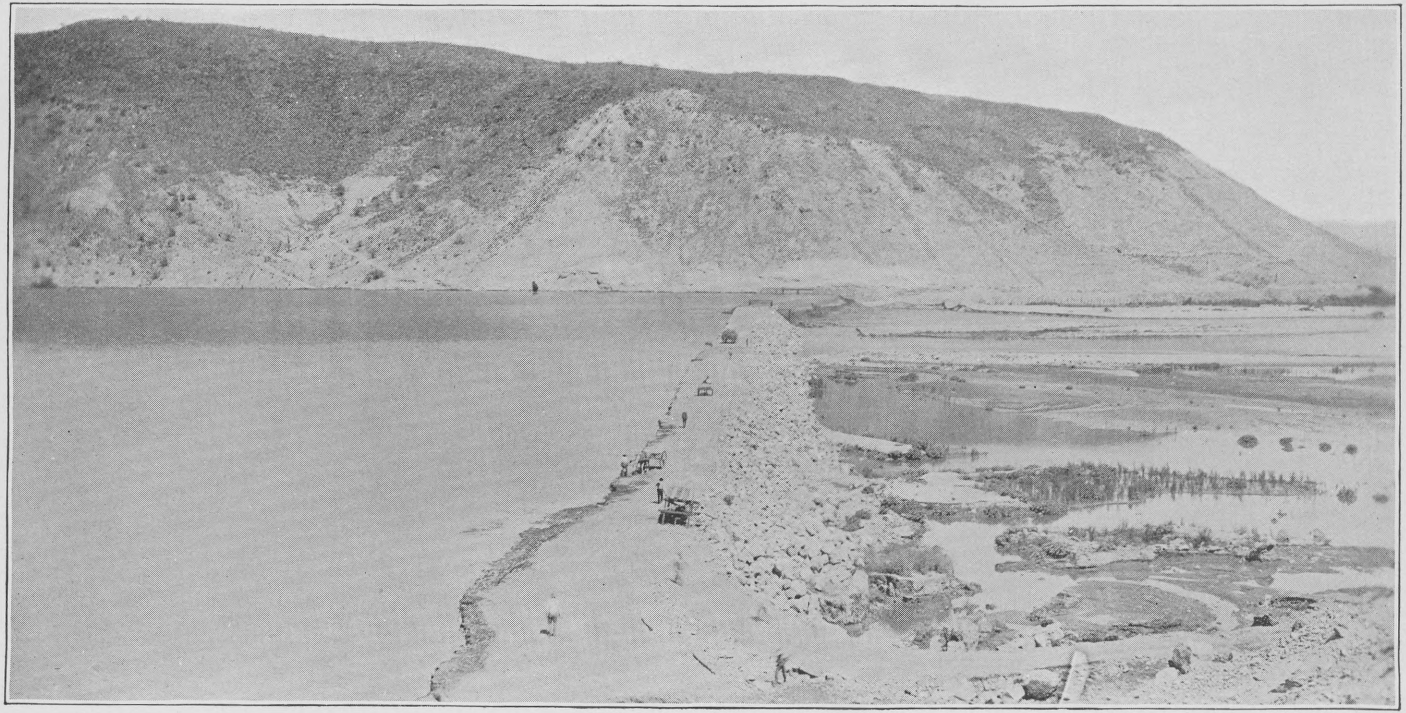
SILT AND ALKALI.

As indicated by its name, Salt River carries a notable quantity of mineral matter in solution. It becomes an interesting question, therefore, whether its use in irrigation will eventually lead to deterioration of the soil through the deposit of alkaline salts. Over most of the valley no such injurious effects are noticeable. This may be due partly to the excess of water applied, which, escaping to the subsoil, carries the salts in solution and bears them away through the gravels to the river bed; and accordingly it is found that where the fields are underlain at a reasonable depth by beds of gravel no accumulation of salts is noticeable, while in the vicinity of Tempe, where the subsoil is practically impervious, and where the ground water is near the surface, considerable tracts of land are to be seen impregnated with alkali, some of it to such an extent as to be of little use in its present condition except for grazing. Inquiry among the inhabitants leads to the conclusion that, although such alkaline indications were noticeable before irrigation became extensive in this valley, these areas have been greatly increased since that time, either from the rise of alkali from the subsoil or from its deposit upon the land by the irrigating waters, for which adequate drainage was not provided. Some tracts of land have even been abandoned from this cause.

It has been stated that a great excess of water is applied in this valley for irrigation and that the progress of methods of economy and the storage of surplus waters in the mountains will undoubtedly lead to a much more sparing application. The question naturally arises, therefore, whether, when the abundant leaching which is provided by the seepage downward of the excess waters is discontinued, the fields in the vicinity of Phœnix and Mesa will not become impregnated with salts to an injurious extent. Any such fear seems to be entirely unfounded. The whole valley, with the exception of the area in the vicinity of Tempe above mentioned, seems to be so thoroughly underlaid with coarse gravel that it will be entirely practicable at any time to leach out the salts by the application of a large quantity of irrigating water for that purpose. At intervals of several years, also, there occur heavy rainfalls in these valleys, which, from their sudden nature and long intervals, can not be depended upon for assistance in agriculture, but which will always be of value for leaching the soil in the manner above referred to.

MIDDLE GILA VALLEY.

There are several ditches built to divert water from the Gila River in Pinal County, but they have all been practically abandoned except the Florence Canal, on the south side, and the McClellan and Arthur ditches, on the north side of the river. This is due to the shortage of water in recent years, caused probably by increased



GILA BEND DAM, LOOKING EAST.

diversions in the upper part of the Gila Basin. The upper or Arthur is a private ditch heading just below The Buttes, without diversion works, and carries about 4 second-feet of water for a distance of about 6 miles, the loss in the sandy river bottom being great.

The McClellan ditch heads about 6 miles below the Arthur, and is a private ditch with a capacity of 14 second-feet. Water is diverted by means of a "burro" dam, which consists of a forked stick driven into the river bed, inclined slightly up stream, supporting in its forks another stick with its end driven diagonally into the sand 6 or 8 feet above. A series of these so-called "burros" are constructed across the stream and support a mass of sticks and brush, which is finally weighted down with rocks and sand. This character of dam is quite common for small ditches in the West, and of course usually requires renewal after the season of high water.

FLORENCE CANAL.

The Florence Canal heads about 3 miles below The Buttes, on the south side of the river. The water is diverted by means of an artificial shoal of rock placed diagonally across the stream. The head-gate of the canal is founded upon bed rock and is constructed of wood. The grade of this canal is about 2 feet per mile. Near the head it is 45 feet in width, and was originally constructed to carry about 4 feet of water, but a shortage of water and financial difficulties have led to the neglect of the banks constructed, so that at present it is not practicable to run much more than 2 feet of water in the canal. Observations of the flow of this canal have been carried on during the year 1896, and are given in the table.

About 20 miles below the head of the canal a reservoir is constructed on the McClellan wash, as indicated on the map (Pl. XXX). This reservoir is formed by an earthen embankment or dike more than 2 miles in length, with a maximum height of about 20 feet. The area of the reservoir is in the neighborhood of 1,800 acres, and the average depth probably 6 or 7 feet. This reservoir has proved to be of great value in conserving the winter waters carried by the Florence Canal when there is an abundance in the Gila River, and also the night discharge of the canal throughout the season, to be used on the lower extension of the canal, which flows westward from the reservoir.

In the absence of any other method of conserving the winter waters such a reservoir is valuable, but as a permanent method of storing the waters of this great stream it is inefficient and wasteful. It can not receive any considerable portion of the great flood waves, as it can receive only the capacity of the Florence Canal, which feeds it. But the chief objection to this method of storage is the great area in proportion to depth which is exposed to the enormous evaporation of this climate. At least three-fourths of the capacity of this reservoir lies within 8 feet of its surface. The annual evaporation in this climate is about 8 feet, so that at all times the loss from this source is a very large proportion of the water impounded. As a method of holding water from year to year it would be practically a failure.

The map (Pl. XXIX) shows the alignment of the Florence Canal, the location of the reservoir, and the location and extent of the irrigated lands. It will be seen that the irrigated lands are scattered, some tracts of not more than 100 acres being situated at a distance of several miles from the canal, with no other irrigated lands in the vicinity. The laterals used to convey water from the canal to these lands are wasteful of water in proportion to the amount utilized, as the amount lost through seepage and evaporation from such small, long ditches is enormous. The loss from this cause and from evaporation in the reservoir accounts abundantly for the low duty of water in this valley. As will be seen by the following table, the total discharge of the Florence Canal through the irrigating season of 1896 was about 64,444 acre-feet:

Discharge of Florence Canal, 1896.

Month.	Discharge in second-feet.			Total for month in acre-feet.
	Maximum.	Minimum.	Mean.	
March (15 days)	160	75	110	3,272
April	160	10	83	4,939
May	42	4	23	1,414
June	12	1	3	179
July	160	0	41	2,521
August	254	27	137	8,424
September	262	117	162	9,640
October	277	0	175	10,761
November	272	168	191	11,365
December	252	160	194	11,929
Total	277	0	112	64,444

The area irrigated above the reservoir was 4,457 acres, and below the reservoir 2,015 acres, making a total of 6,472 acres from which crops were matured in 1896, and these were largely of the grains. It will be seen, therefore, that nearly 10 acre-feet of water flows through the Florence Canal for each acre irrigated, being sufficient, if actually upon the land, to cover it to a depth of nearly 10 feet. The statement of areas irrigated was furnished by Mr. A. T. Colton, who was employed to measure them by the Florence Canal Company.

LOWER GILA VALLEY.

Under the term "Lower Gila Valley" may be included that portion of lowlands along Gila River beginning at the mouth of Salt River and extending to Yuma, a distance by the river, omitting minor bends, of about 170 miles. In altitude it is the lowest part of Arizona, the height

GILA BEND DAM, SPILLWAY AND HEADWORKS.

of the Southern Pacific Railroad at the town of Gila Bend being given as 737 feet, and of Yuma, at the mouth of Gila River, 40 feet. Both of these towns are considerably above the level of the bottom lands. In consequence of its low elevation the temperature is extremely high, and were it not for the aridity of the climate the summer heat would be almost unbearable. The lands along the river are of great fertility, and where watered produce abundant crops. The Southern Pacific Railroad extends in a general way parallel to the river and from 2 to 10 miles away, except above Gila Bend, where the river describes a great loop. The irrigating systems are, on the north side, the Buckeye and Monarch canals, and on the south side of the river Rumberg's ditch, Gila Bend Canal, and Upper Gila or Palmer Canal. Farther down, below Gila Bend, are a number of other systems, lying beyond the limits of the area described in this paper.

BUCKEYE CANAL.

The Buckeye Canal was begun in 1885, and water was first used in 1888. It heads on the north side of Gila River, about 4 miles below the junction of Salt River, and just below the mouth of the Agua Fria. The ownership is divided into shares, each of these representing 80 miner's inches. It is about 25 miles in length, and is built on a grade of 2 feet to the mile. At the head it is 19 feet wide, and has a depth of about 3 feet, and a capacity of about 75 cubic feet per second. It has 22 small laterals, and the main canal of course decreases in size as the laterals are taken out.

GILA BEND CANAL.

The dam of the Gila Bend Reservoir and Irrigation Company (Pl. IX) is located about 40 miles southwesterly from Phœnix and 25 miles north of the Gila Bend Station, on the Southern Pacific Railroad. It is nearly 2,400 feet long, and as originally planned was to be an overflow weir built of timbered cribs loaded with rock and anchored to piles driven in the bed of the river. After the completion of about 600 feet of the east end the expense involved induced the company to alter the plans and to build the remaining portion of loose rock, the part already constructed being intended as a waste weir, and the rock portion was built about 6 feet higher (Pl. X). The top width of the rock portion was about 18 feet, and the side slopes 1½ to 1. From the first, serious doubts of the stability of the dam were entertained by those competent to judge. It was generally conceded that the first water which overtopped the loose rock portion of the dam would wash it out. In view of this fact, and the published records of the discharge of the river showing floods approximating 300,000 cubic feet per second, it is a matter of surprise that the capacity of the waste weir was left at only about 30,000 cubic feet per second.

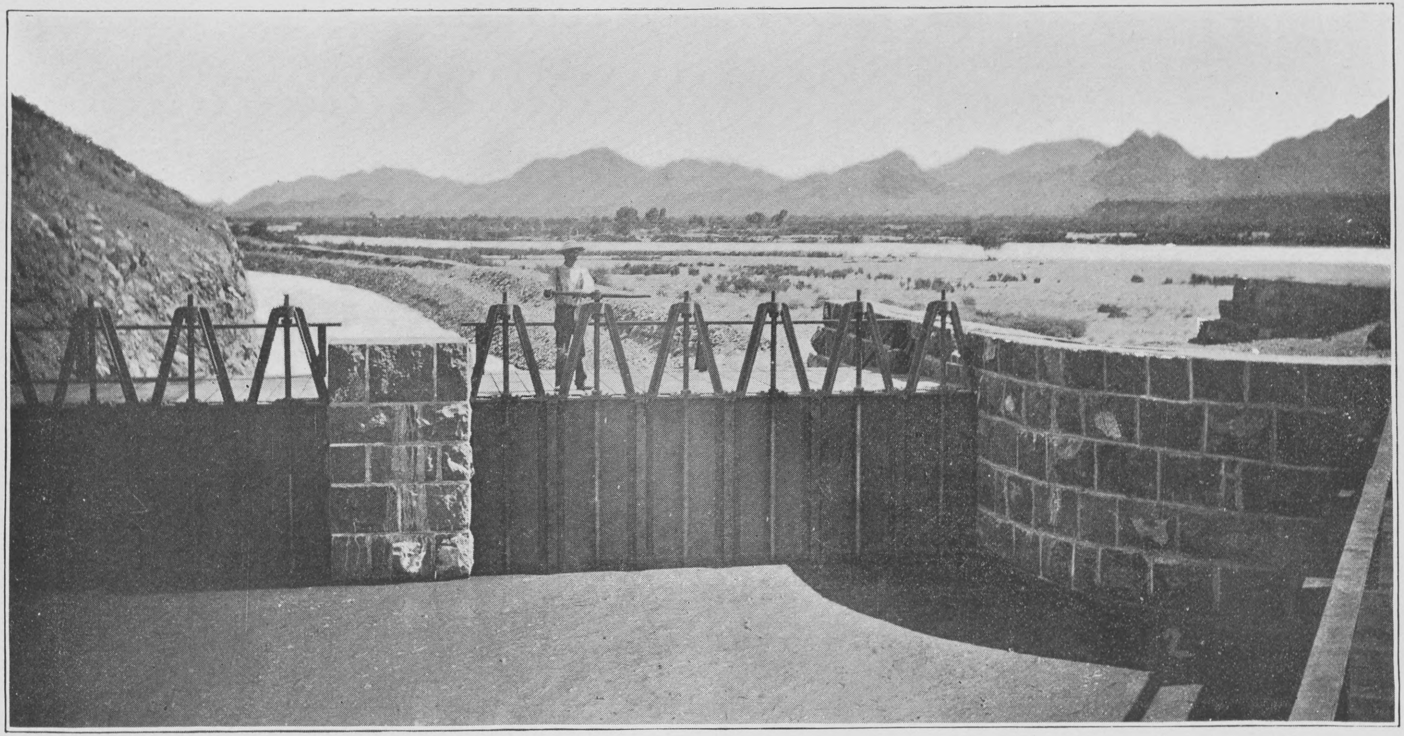
The first indication of a failure was in January, 1893, when a slight rise in the river caused the loose rock portion of the dam to settle several feet. This portion was raised to its original height, and the dam was declared completed, at a cost of nearly $200,000. In March of the same year a heavy flood washed out 500 feet of the dam near the center. This breach was repaired, and in October of the same year, when the river rose again, 400 feet at the west end of the dam went out. It was now decided to make the dam a waste weir extending entirely across the river, and plans were drawn up and operations begun accordingly. The original wooden portion of the dam was thoroughly overhauled and all warped or defective timbers were taken out and replaced by new ones, and the crest of the weir was raised 2½ feet. In the portion built originally of loose rock several rows of piling were driven from 13 to 18 feet into the bed of the river. They were cut off and framed over with heavy 10-inch by 12-inch timbers. The crest of the new portion stood 2½ feet above the raised crest of the old weir. The new design also called for sheet piling above and below the dam for its entire length and a row of detached cribs below the aprons on the lower side. In January, 1895, before the new work was completed, another freshet ran about 8 feet deep over the entire length of the dam, discharging nearly 180,000 cubic feet per second, and washing out the uncompleted portion of the dam for about 400 feet from the west end, which has not been replaced. The property of this company is in litigation, and further repairs and development must await settlement of legal questions.

The canal was begun in May, 1892, and completed the following year. Its total length is 38 miles, with varying bottom widths, gradients, and depths, as shown in the following table:

Dimensions of the Gila Bend Canal.

Length.	Gradients per mile.	Bottom width.	Depth.
Miles.	*Feet.*	*Feet.*	*Feet.*
½	0.5	30	10
5½	0.5	25	10
6	0.5	24	10
6	0.5	23	10
6	0.5	22	10
7	0.6	20	10
4	0.7	15	9½
3	0.8	10	9

The side slopes were 1:1 in cut and 1½:1 in fill. The level section of the canal was a cut of 4½ feet, with embankments of 5½ feet on either side, with berms of 2½ feet. Nine flumes, aggregating 424 feet in length, were substantially built of wood. Twenty-one single and 2 double culverts, consisting of 24-inch cement pipe and aggregating 2,705 feet, were inserted. About 75 miles of laterals have been con-



GILA BEND CANAL HEADGATES.

structed. The head-gates are large iron structures between massive masonry abutments and wing walls. (See Pl. XI.) The head-gate and canal may be taken as one of the best and most substantial works of the kind yet constructed. The entire project is reported to have cost about $1,000,000.

About 10 miles below the Gila Bend Reservoir and Irrigation Company's dam the lower Gila Bend Canal heads, on the same side of the river, and covers a narrow strip of land about 15 miles in length. It is 11 feet wide, and is said to have cost about $25,000. It was first used in 1885. Water is diverted by means of a temporary dam of brush and stone, which is renewed when required. It is a cooperative concern, owned by the irrigators in the form of 36 shares, each entitling the holder to a proportionate part of the water.

SALT RIVER VALLEY.

As previously defined, Salt River Valley is taken as including the lands adjacent to Salt River extending from the mouth of its principal tributary, the Verde, down to the point where Salt River empties into Gila River, a distance in a direct line of about 40 miles. The fall of the river between these points is so great that water can be readily diverted at almost any part of the river's course and carried diagonally away from the stream, covering in the course of a few miles a considerable extent of country. As shown by the map (Pl. XXX), canals have been constructed heading at short intervals from near the upper end of the valley down along its whole course. The principal of these canals are shown in the following list, which gives also the approximate length and the year when first used. These canals have an aggregate of nearly 600 miles of lateral ditches.

Principal canals of Salt River Valley.

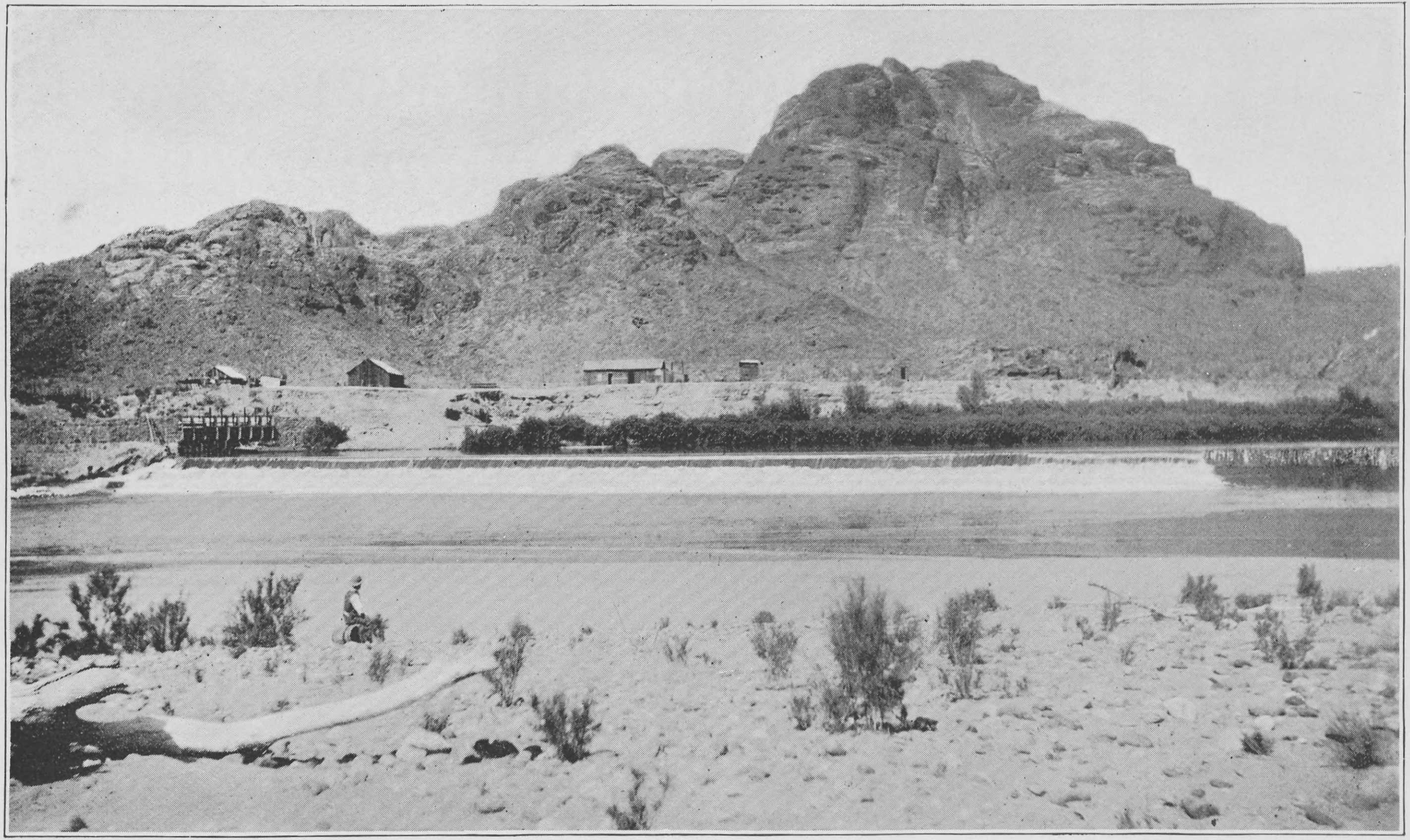
Name.	Length.	When first used.
	Miles.	
NORTH SIDE.		
Arizona	47	1885
Grand	27	1878
Maricopa	26	1868
Salt River Valley	19	1868
Farmers'	5	....
St. Johns	12	....
SOUTH SIDE.		
Highland	22	1889
Consolidated	40	1894
Old Mesa	10	1878
Utah	20	1877
Tempe	30	1871
San Francisco	6	1871

The following description gives the principal facts obtainable concerning these canals, the descriptions being arranged in geographic order, first those on the north side and then those on the south.

ARIZONA AND OTHER NORTH-SIDE CANALS.

The Arizona Canal, constructed in the years 1883 and 1884, heads highest on the river and has the only permanent dam. This dam, or weir, is located about 1 mile below the mouth of the Verde, and extends diagonally across the river in a northeasterly direction from a rock projecting into the stream from the right bank to a rock on the left bank. At the time of its construction the river channel was against the right bank, and on the left side a gravel bar sloping from the channel to the bank extended to a depth of 8 or 10 feet. This bar was excavated to the surface of low water for a width of 60 feet, and the dam was begun with mudsills 8 inches by 10 inches by 48 feet, laid parallel with the stream at intervals of 10 feet. Upon the upstream half of these sills is built a continuous crib with cross-ties every 10 feet, into which the rails are gained, a space of 4 inches being left between the rails, which are fastened with 12-inch drift bolts three-fourths inch in diameter. The front and back sides of the crib have a batter of one-fourth to one, and are covered with 2-inch plank with 6-inch sheet piling drifting at its back. The rail is laid lengthwise on mudsills in the center of the crib, and constitutes the only floor of the crib, which is filled with bowlders.

The crest of the dam for a distance of 416 feet on the left bank is 10 feet above low water and is covered with 3-inch plank, spiked to the rails and braced and propped from cross-ties below, and having a slope of 3 feet upstream. Rails are laid upon the mudsills projecting 24 feet downstream, 4 feet apart, and covered with 3-inch plank for apron, and sheet piling 3 inches thick and 18 feet in length driven at lower edge of apron. Below the apron the gravel was excavated and cribs put in 4 feet deep and 12 feet wide, of various lengths from 10 to 24 feet, with double rods to bind corners. These cribs were filled with rock and covered with 3-inch plank. The portion of the dam just described is still standing. The part built across the channel was constructed similarly, and went out in the great flood of 1891 and was replaced by a more substantial structure, having the overfall broken into a series of steps, and the 5-foot sections of dam bound together with $1\frac{1}{4}$-inch iron rods from top to bottom. Sheet piling was driven at both the heel and toe of the renewed portion. The current strikes the crest of the dam at an angle of about 12°. Between the southwest end of the dam and the canal head-gates a wasteway was blasted out of the rock 36 feet in length, and prepared to receive slash boards, which can be easily removed when necessary to draw off the water from the back of the dam during low water for repairs. The total distance at high water over the dam wasteway and rock on level with dam is 1,000 feet.



VIEW OF ORIGINAL ARIZONA DAM.

GREAT FLOOD OF 1890 ON SALT RIVER.

The head works of the canal are in solid rock, with masonry abutments and wing walls and wooden gates. The bottom width of the canal is 36 feet at the head, and becomes narrower toward the lower end. The estimated capacity is 1,000 cubic feet per second. For the first 3 or 4 miles there is considerable heavy construction, the country being somewhat rough, and the material to be moved consisting largely of gravel, with some solid rock. The canal was first used in 1885. It is 47 miles long, and cost $600,000.

Grand Canal, heading about 2½ miles above the consolidated head of the Salt River Valley and Maricopa canals, was constructed in 1878. The capacity of this canal is 215 second-feet. It has been absorbed by the Arizona Canal Company, its head works have been abandoned, and it receives water from the Arizona Canal through what is called the Crosscut Canal. This latter was constructed in 1889, partly for the purpose of economizing the water to which the Grand Canal is entitled by carrying it through the Arizona Canal instead of through the sandy bed of the river, and partly to utilize for power purposes the fall between the Arizona and Grand canals. Its capacity is about 375 second-feet, and it supplies water for the Grand Canal, and at times during low water for the Salt River Valley and Maricopa canals.

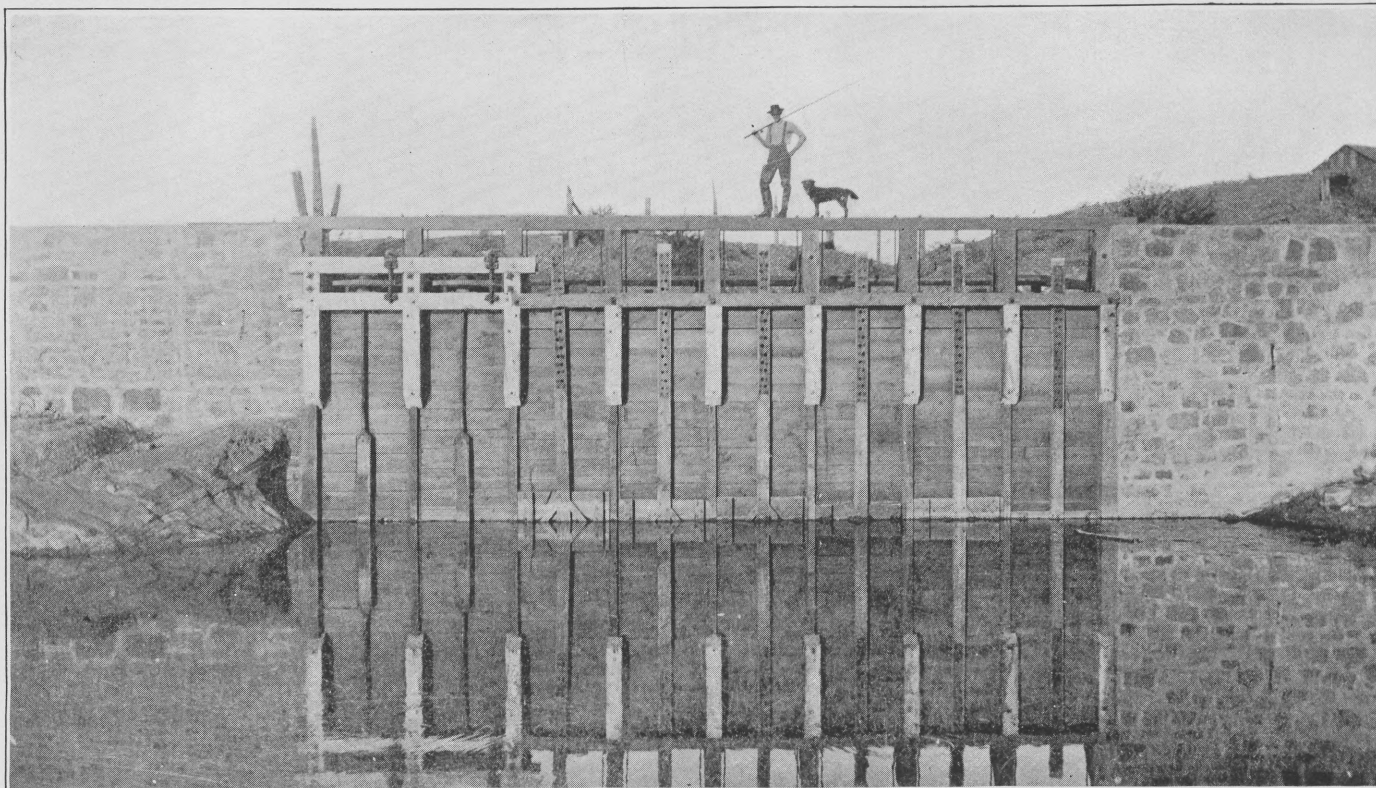
The oldest diversion from Salt River for irrigation purposes is the Salt River Valley Canal, constructed in 1867 by Jack Swilling and his associates, and called originally the Swilling Ditch. It is on the north side of the river, about 5 miles east of Phœnix. Some time after its construction another canal or branch was taken from it, at a point about 3 miles below its head, which became known as the Maricopa Canal. These two canals with a common head are sometimes called the Consolidated Canals. The diversion is by means of an artificial shoal formed of rocks and brush through wooden head-gates, with solid masonry abutments and wing walls. The capacity of Salt River Valley and Maricopa canals jointly is about 275 second-feet. Both canals are now controlled by the Arizona Canal Company.

SOUTH-SIDE CANALS.

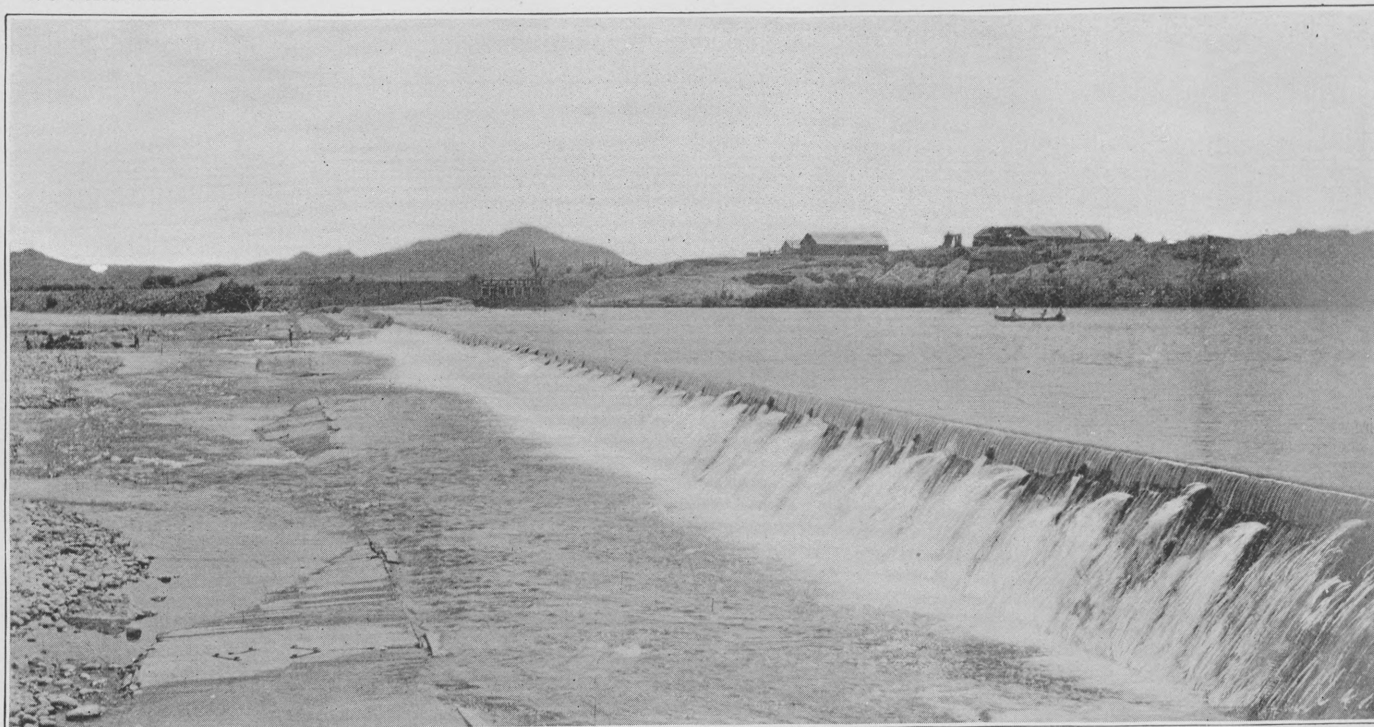
The Highland Canal was built early in 1889. It takes water on the south side of the river, about 2 miles below the head of the Arizona Canal, and has a capacity of about 100 cubic feet per second.

The Mesa City Canal was begun in 1879 by the Mesa Canal Company, a corporation composed of the owners of the land to be watered by the canal. It emerges from the river on the south side, about 2½ miles above the head of the Utah Canal, being above the head of all the canals and ditches previously constructed. It supplies water to Mesa City and adjoining country, and has a capacity of about 175 second-feet. Its alignment for a considerable distance is said to have followed the line of one of the prehistoric canals of this valley. One share of stock in this canal represents a maximum of 17½ miner's inches, or a little over two-fifths of a cubic foot per second. The water represented by a share supplies about 40 acres of land and is valued at present at about $250. The annual charge per share is $14. Considerable expense and annoyance was experienced for many years from the insecure head works of this canal, the farmers frequently being obliged to quit work in the busy season to restore their supply of irrigating water. Finally, in 1893, the Consolidated Canal Company was formed, which entered into a contract to build new head works and to deliver a specific quantity of water for a consideration at a designated point on the Mesa Canal for the use of the owners of that canal. This company built a shoal of large bowlders across the river, which withstands the floods of the river, but it gradually settled, at first into the sand and gravel of the river bed. As settlement proceeded it has been built up and constitutes a very fair means of diversion. At the south end of this shoal are built massive granite masonry abutments and wing walls, between which the canal flows through wooden gates directly into the mesa of bowlders and hardpan, through which it is constructed in a deep cut for a distance of over 2 miles, the maximum cut being about 26 feet. This heavy construction was performed by a huge dredge with a dipper capacity of 2 cubic yards of earth and having a lift of 26 feet. At the end of these 2 miles the Consolidated Canal follows for some distance the alignment of the Mesa Canal until it reaches a point about 3 miles northeast of Mesa City, which is designated as the point of delivery of the specific quantity of water for the irrigators under the Mesa Canal. At this point the water for the Mesa Canal Company is discharged into their old canal, and two branches are constructed by the Consolidated Canal Company, one starting southeast for irrigating purposes, and one running due west for about 2 miles until it reaches the edge of the mesa, just above the Tempe Canal, where a large power plant is constructed for electric lighting and power purposes, using the irrigating water to which the Tempe Canal is entitled and discharging it from the wheels into the Tempe Canal about 1½ miles below its head. For some time the right to use the irrigating waters of the Tempe Canal was questioned, but this matter is now said to be adjusted. The eastern branch of the Consolidated Canal above mentioned is constructed on a light-grade line, in a general southerly direction, to the boundary of the Gila River Indian Reservation. By carrying the water of the Tempe Canal through the Consolidated Canal instead of through the sandy river bed, a considerable loss by evaporation is prevented, and the water available for irrigation is thereby increased. In this manner the Consolidated Canal obtains a right to some irrigation waters.

The Utah Canal was constructed in 1877 on the south side of the river, heading about 5 miles above the head of the Tempe Canal. It was constructed and is operated by the owners and occupants of the



ARIZONA CANAL HEADGATES.



VIEW OF PRESENT ARIZONA DAM.

lands which are irrigated by its waters, and the association is unincorporated, the water rights being represented by certificates which are transferable. Its capacity is about 175 second-feet.

In 1870 a ditch was constructed on the south side of the river, known as the Tempe Irrigating Canal. It heads about 7 miles above the Salt River Valley Canal, and was carrying in June, 1896, about 114 cubic feet of water per second. This is a community ditch, the property of the owners of the land irrigated from it, the shareholders being unincorporated. The canal has a carrying capacity of 337 cubic feet of water per second.

The San Francisco Canal, known also as the Wormser Canal, was constructed on the south side of the river in 1875. It heads a short distance below the town of Tempe, and has a capacity of about 52 second-feet.

Mr. C. T. Hayden, a shareholder of the Tempe Canal Company, in the year 1874 erected a flouring mill at Tempe, and by an arrangement with the other shareholders obtained a supply of 27½ cubic feet of water per second to run his mill.

AREA IRRIGATED.

It is extremely difficult to obtain reliable figures concerning the area irrigated in any locality. This is true in the Salt River Valley as elsewhere, and is due not only to the fact that farmers as a rule do not keep records of the results of their labors, but also because of the many influences tending toward exaggeration of statements. It is usually to the interest of the farmer as well as the canal owner to claim that a large area is irrigated, so that in case of subsequent controversies over water rights his title to the use of water may be supported. The matter of definition also, as to what may be considered as irrigated, introduces complications. In order to secure title under the desert act, claims are made and proofs submitted that hundreds of acres are irrigated, although as a matter of fact this irrigation is of the most nominal character, and to the eye the land has received no apparent benefit.

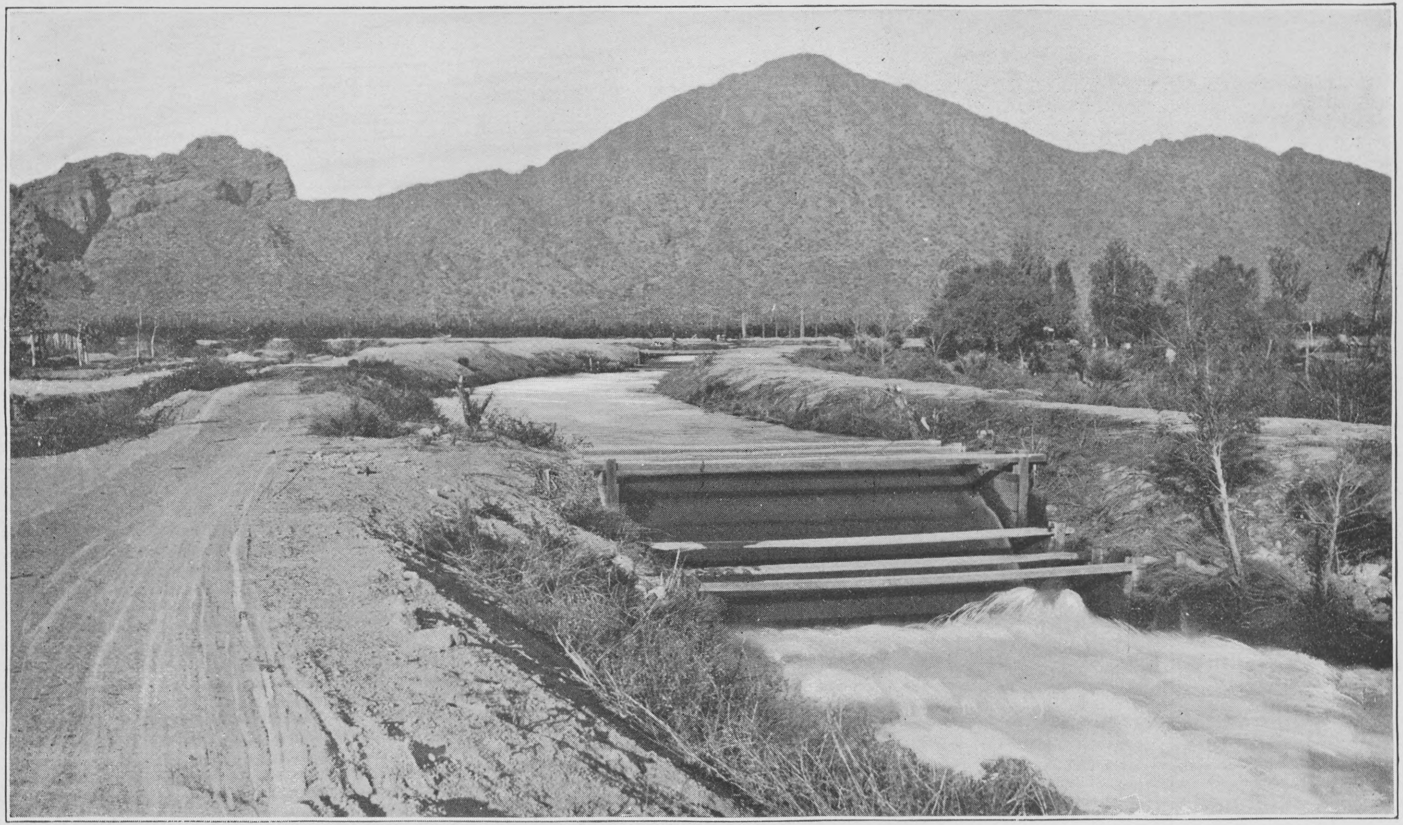
A systematic attempt was made by the Eleventh Census to obtain an exact statement as to the amount of land actually irrigated and cropped in the census year 1889. A farm-to-farm enumeration was made for the purpose of obtaining the area of land in each farm, the amount improved, cultivated, and irrigated, the area and quantity of crops, and many other details. It was found during this census that claims were frequently made that 160 acres were irrigated, when the crops aggregated only about 30 or 40 acres. Examination revealed that as a rule the amount claimed as irrigated represented the amount of land under ditch and to which water might perhaps be taken; while actually, either from deficiency of water or other cause, successful irrigation was conducted only upon the smaller area.

The total area irrigated in Arizona and from which crops were obtained during the season of 1889, according to the Eleventh Census, was only 65,821 acres, the greater part of this being in barley, alfalfa, and other forage crops. Of this amount, the area irrigated in Maricopa County was found to be 35,212 acres. A large portion of this was on the south side of Salt River. For comparison, and to illustrate the difference obtained by estimates based upon the claims of canal owners and farmers, it is stated that on the north side of Salt River, in Maricopa County, there were irrigated in 1889, under the Arizona Canal, 56,000 acres. This amount, or 350 quarter sections, is the quantity given in the decision noted later on page 61. The area given as irrigated from the Arizona Canal system in 1895 was about 60,000 acres. The discrepancy between the census figures and the amount adjudicated may be due to a number of causes, but is probably accounted for largely by the fact that many of the tracts to which water rights were adjudicated were cultivated only in part, and did not yield crops of sufficient size to be reported by the owners or enumerators. Many of the tracts formerly claimed as irrigated have since the acquisition of title been left uncultivated. It is suggestive to note in this connection that the adjudicated rights of some of the older canals aggregate more than their entire capacity.

The first irrigation under the Arizona Canal occurred in 1885. The decision handed down by Judge Kibbey (page 61) adjudicated rights for the year 1884 aggregating 82,600 acres. On the basis of the duty of water assumed by the court—100 acres per second-foot—it would require for the satisfaction of these rights a flow of 826 cubic feet per second. By reference to the table of discharges of Salt River at Arizona dam, on page 37, it is seen that the mean flow for the month of July in 1889 was 495 second-feet, and for the same month in 1890 it was 524 second-feet. The flow for the month of June, which it would be safe to assume as available for irrigation, would be not more than 500 cubic feet per second, whereas in the year 1884, as just shown, before the Arizona Canal was brought into use, 826 second-feet were required to satisfy the legal rights existing in the valley. But crops of grain can be matured in this valley by the growth in the winter and spring, and large areas are undoubtedly matured every year before the 1st of June. The minimum flow for the month of May, however, is given as 622 second-feet in 1889, and as 630 second-feet in 1890, while the mean for the entire month in 1890 is 914 second-feet.

The two minima given would seem to indicate that a shortage was imminent even in the month of May in 1884, if the rights as adjudicated were all claimed. If this was the case in 1884, what can be said of 1889, when instead of 82,600 acres claiming water there have been adjudicated rights amounting to 151,360 acres? The areas that have been irrigated since 1889 under the Arizona Canal system have probably been increased, so that the total area using or claiming water

FALLS ON ARIZONA CANAL.



VIEW ON CROSSCUT CANAL.

from Salt River is double what it was in 1884, and consequently more than double the capacity of the river to supply in ordinary years, and still more beyond its capacity in dry years. But the condition of irrigation in Salt River Valley is not as bad as these figures would seem to imply. As above indicated, the adjudicated rights are probably greater than the areas actually irrigated in the years given, and cultivation has been discontinued on some of the tracts formerly irrigated. There is considerable competition for water among irrigators during the dry months, and this has been one cause of the abandonment of areas formerly cultivated.

ADJUDICATION OF WATER RIGHTS.

It will readily be seen by the foregoing that the various canals and ditches taking water from Salt River have an aggregate capacity much larger than the low-water flow of the river, which is in the neighborhood of 300 cubic feet per second, and the irrigable land under these canals is proportionately in excess of the water supply in the dry season.

These facts led to the institution of a suit before Judge Joseph H. Kibbey to determine the rights of the various proprietors, the trial of which was begun in March, 1890, and concluded in August of that year. The amount of evidence taken in the case is very voluminous, consisting of 6,000 pages of typewritten matter. The argument of the case was heard in February, 1891, and occupied fifteen days. Many interesting principles of the law relating to water rights were enunciated in this decision, relating to the method of acquiring water rights and the rights of the community concerning the reasonable use as opposed to the waste of water. This decision was published, but the pamphlet is now out of print, and a portion of the decision is here reprinted on account of its value and interest in connection with this subject.

JUDGE KIBBEY'S DECISION.

In 1848, and from that time until 1863, that part of the Territory of Arizona within which is the Salt River Valley was a part of the Territory of New Mexico, and there were expressly enacted by that Territory laws governing the appropriation and use of water for irrigation. In 1863 part of the then Territory of New Mexico was erected into a temporary government by the name of the Territory of Arizona, and the laws of New Mexico were, by the acts of Congress establishing the Territory of Arizona, made applicable to that Territory.

In 1864 the First legislative assembly of the Territory convened and enacted the code of laws commonly known and cited as the Howell Code. By article 22 of an act of that legislature, known and designated as the "Bill of Rights," it was provided that "all streams, lakes, and ponds of water capable of being used for the purposes of navigation or irrigation are hereby declared to be public property, and no individual or corporation shall have the right to appropriate them exclusively to their own private use, except under such equitable regulations and restrictions as the legislature shall provide for that purpose." This act went into force on the 1st day of January, 1865. This provision has been incorporated in the successive revisions of our code, and is still a part of our statutory law. At the same session of the legislature, and by a law taking effect at the same time, an act governing acequias and irrigating canals was adopted.

Section 1 of that act provides that "all rivers, creeks, and streams of running water in the Territory of Arizona are hereby declared to be public and applicable to purposes of irrigation and mining," as afterwards provided.

Section 2 saves all vested rights.

Section 3 provides that "all the inhabitants of this Territory who own or possess arable or irrigable lands shall have the right to construct public or private acequias and obtain the necessary water for the same from any convenient river, creek, or stream of running water."

Section 4 provides for the assessment of damages resulting from the construction of ditches across private property of individuals.

Section 5 provides that no inhabitant of this Territory shall have the right to erect any dam, or build a mill, or place any machinery, or open any sluice, or make any dike, except such as are used for mining purposes or the reduction of metals, as provided for in sections 6 and 7 in the act, that may impede or obstruct the irrigation of any lands or fields, as the right to irrigate the fields and arable lands shall be preferable to all others, and the justices of the peace of their respective precincts shall hear and determine the question relative to all such obstructions in a summary manner and cause the removal of the same by order directed to a constable of the precinct or sheriff of the county, who shall proceed to execute the same without delay.

Section 7 directs that when any ditch or acequia shall be taken out for agricultural purposes the person or persons so taking out such ditch or acequia shall have the exclusive right to the water, or so much thereof as shall be necessary for the said purposes, and if at any time the water so required shall be taken for mining operations the person or persons owning said water shall be entitled to damages, to be assessed in the manner provided in section 6.

Section 8 prohibits the construction or maintenance of bypaths and footpaths across cultivated fields.

Section 9 provides that all owners and proprietors of arable and irrigable lands bordering on, or irrigable by, any public acequia shall labor on such public acequia, whether such owners or proprietors cultivate the land or not.

Section 10 provides that persons interested in a public acequia, whether owners or lessees of land, shall labor thereon in proportion to the amount of land owned or held by them which may be irrigated by the ditch.

Section 11 provides that animals shall be herded to prevent trespass upon cultivated fields.

Section 12 provides that in case a community desire to construct an acequia and the persons desiring to construct the same are the owners or proprietors of the land upon which they design to construct the acequia, no one shall be bound to pay damages for the land taken.

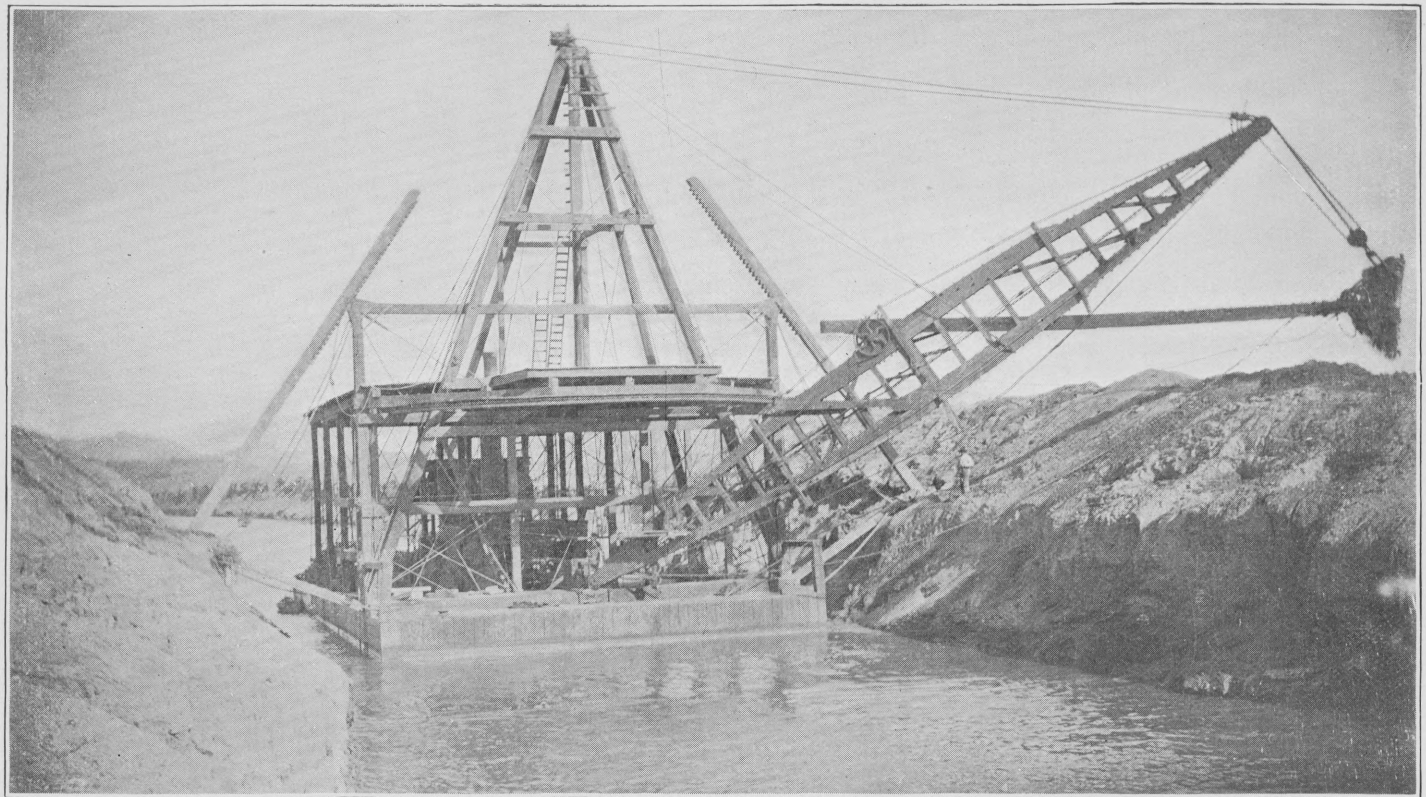
Section 13 provides for the election of overseers of public acequias.

Section 14 prescribes the manner of the election of overseers.

Section 15 provides for payment for services of the overseers.

Section 16 prescribes the duty of the overseers, of which, among others, is enumerated the duty to distribute and apportion the water in proportion to the quantity to which each one is entitled according to the land cultivated by him, and that in making such apportionment he shall take into consideration the nature of the seed sown or planted and the crops and the plants cultivated.

Section 17 provides that "during years when a scarcity of water shall exist owners of fields shall have precedence of the water for irrigation according to the dates of their respective titles or their occupation of their lands either by themselves or their grantors. The oldest titles shall have precedence always."



MAMMOTH DREDGE EXCAVATING MESA CONSOLIDATED CANAL.

Section 18 provides for the contribution of labors by irrigators to the maintenance of the acequia.

Section 19 prescribes penalties for malfeasance or nonfeasance of the overseer in discharging his duties, and provides for his removal in certain events.

Section 20 provides for the filling of the vacancy occasioned by the removal of the overseer.

Section 21 imposes a penalty upon the owner or proprietor of land irrigated by an acequia for neglect or refusal to furnish the number of laborers required by the overseer for the maintenance and repair of the acequia.

Section 22 prescribes the penalties against any person who shall in any manner interfere with, impede, or obstruct any such acequia or use the water from it without the consent of the overseer.

Section 23 provides that the fines and forfeitures recovered under the provisions of the act shall be applied by the overseers to the improvement, excavation, and repair of the acequia, and for the construction of bridges at points where they may be crossed by public streets or roads.

Section 24 provides for the appeal from judgment of conviction under any of the provisions of the act.

Section 25. "The regulation of acequias which have been worked according to the laws and customs of Sonora and the usages of the people of Arizona shall remain as they were made and used up to this day, and the provisions of this chapter shall be enforced and observed from the day of its publication."

Section 26 provides that plants and trees growing on the banks of any acequias shall belong to the owners of the land through which the acequia runs.

Section 27 provides that any person owning lands which may include a spring or stream of running water, or owning lands upon a river where there is not population sufficient to form a public acequia, may construct a private acequia for his own uses, subject to his own regulations, provided he does not interfere with the rights of others.

In the year 1866 the National Congress enacted a law for the disposal of its lands containing valuable minerals, and among the provisions of that act, with some subsequent slight verbal changes not affecting the substance or meaning, is the following (sec. 2339, Revised Statutes of the United States):

"Whenever by priority of possession rights to the use of water for mineral, for mining, agricultural, manufacturing, or other purposes, have vested and accrued, and the same are recognized and acknowledged by the local customs, laws, and decisions of courts, the possessors and owners of such vested rights shall be maintained and protected in the same, and the right of way for the construction of ditches and canals for the purposes herein specified is acknowledged and confirmed; but whenever any person, in the construction of a ditch or canal, injures or damages the possession of any settler upon the public land, the party committing such injury or damage shall be liable to the party injured for such injury or damage."

Section 2340 provides "that all patents granted, or preemption or homestead allowed, shall be subject to any vested or accrued water rights, or rights to ditches or reservoir used in connection with such water rights, as may have been acquired under or recognized by the preceding section."

This provision of the act of Congress has been held by the Supreme Court of the United States, and of some of the States, not only to confirm rights that have been initiated or had vested prior to the passage of the act, but that it was continuous in its operation and was the license of the Government to persons to hereafter appropriate water on the public domain for agricultural, mining, manufacturing, or other purposes. (98 U. S., 453; 13 Oregon, 596.)

On the 3d of March, 1877, there went into effect an act of Congress providing that any citizen of the United States, or any who had declared his intention to become such, upon the payment of 25 cents per acre, may file a declaration, with the register and receiver of the land district in which any desert land is situated, of his intent to reclaim a tract of land not exceeding one section, by conducting water thereon within the period of three years thereafter. It provides that the right to the use of the water by the person so conducting the same on or to any tract of desert land of 640 acres "shall depend upon bona fide prior appropriation, and such rights shall not exceed the amount of water actually appropriated and necessarily used for the purposes of irrigation and reclamation, and all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers, and other sources of water supply upon the public lands and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes, subject to existing rights."

By an act of the legislative assembly of the Territory of Arizona approved February 19, 1877, all the laws of the Territory then in force were directed to be recompiled, which was done; and the compilation is known and cited as the "Compiled laws of 1877," among which are the Bill of Rights and the various provisions governing the construction of private and public acequias and the appropriation and use of water for irrigation that we have above quoted from the Howell Code. The same laws have been carried forward into the revision of 1887. In 1887 the acequia law was not reenacted, but not having been repealed, it is still in force, and the editors of the revision of 1887 have incorporated it in that revision. (Sects. 3199-3226, R. S., 1887, Arizona.)

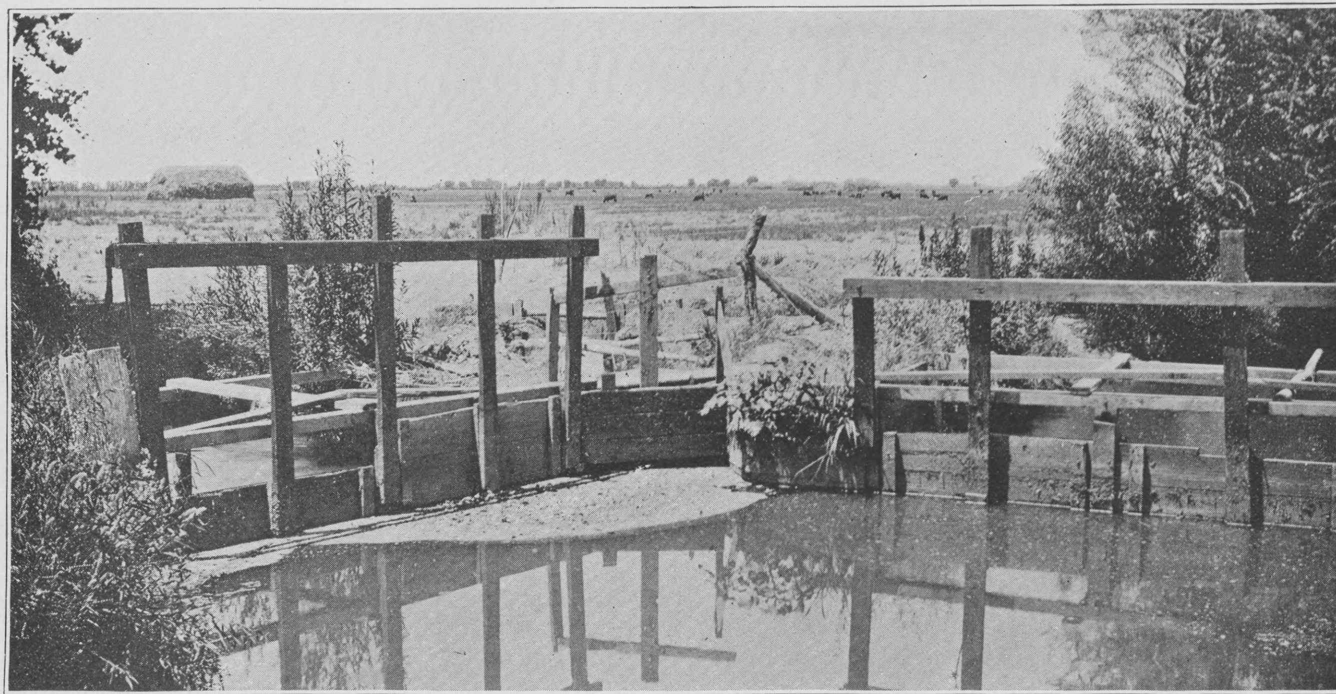
In 1887 the legislative assembly enacted a law providing that the common-law doctrine of riparian rights shall not obtain or be of any force or effect in this Territory. (Sec. 3198, R. S., 1887. Arizona.)

* * * * * * *

REASONABLE USE OF WATER.

Incident to the right of the inhabitants of this Territory to appropriate water for irrigation or other uses is the restriction that the means of diversion shall be reasonably adapted to the purpose, to the end that the water that is made free to the public shall not be diminished beyond the quantity sufficient to supply the actual needs of the appropriator; that the means of application of the water to the purposes for which it is appropriated shall be of a character to insure as small a consumption of water as is reasonably consistent to the accomplishment of that purpose. No man has a right to waste a drop of water. Any excess of water that he diverts and wastes by carelessness, negligence, or ignorance of economic methods of cultivation or irrigation, or failure to adopt them, he unlawfully diverts.

It appears from the evidence in this case that large quantities of water are allowed to flow in the various canals and ditches to supply stock with water. This necessarily involves a great waste of water. At a small estimate, I should think the evidence discloses an amount of water wasted thus sufficient, if properly applied to irrigation, to make productive 10,000 acres of land. The amount of water actually consumed by the stock is insignificant. The loss is that due to evaporation and seepage in its long passage through the various canals and the miles of subsidiary ditches. This seems to me to be an unreasonable use of water. I do not mean to deny the right to the use of water for stock, for it has always been a recognized use, like that for domestic purposes. But it can not, I think, be diverted from its original course for that purpose. It has always been the law that stock and the public could drink from a water course, but not to impede its flow or diminish its quantity for that purpose. Instead, I consider the law to be, of bringing the water diverted from a natural water course a long distance by means necessarily involving an enormous proportionate waste to water stock, the stock must be taken to the natural water course to drink, or otherwise provided for.



DIVISION BOX ON TEMPE CANAL.

If the water be in the ditches on a man's ranch in the course of application directly to irrigation, it might be permitted to allow stock to drink of it; but it is an unreasonable use of it to permit water to be in the ditches for that purpose alone.

Another matter for our consideration in this connection is the right of the appropriator of water to the exclusive possession, maintenance, operation, and the use of the conduit, as he has prepared it, for the diversion of the water, whether or not, having constructed such a conduit, he thereby has the right to have the water flow in the river to that conduit and thence to the point where he desires to use it, or whether his right is limited to the actual delivery of water to his lands, with or without increased expense to himself, whether it be by means therefor provided by himself or by means provided by some one else. To illustrate: If those who operate the Highland Canal should divert from the river the water to which the consumers under the Tempe, the Mesa, the Utah, and the San Francisco are entitled, and yet should that company deliver the water so diverted through its own canal to and upon the lands of those under the other canals named, in the quantities to which they are entitled, would those who constructed and since have operated and maintained the Tempe Canal, the Utah Canal, the Mesa Canal, and the San Francisco Canal have any just cause for complaint, or have the owners of those mentioned canals a vested right not only to the use of the water for the purpose of irrigation, but also to have it conveyed by means of its own conduit?

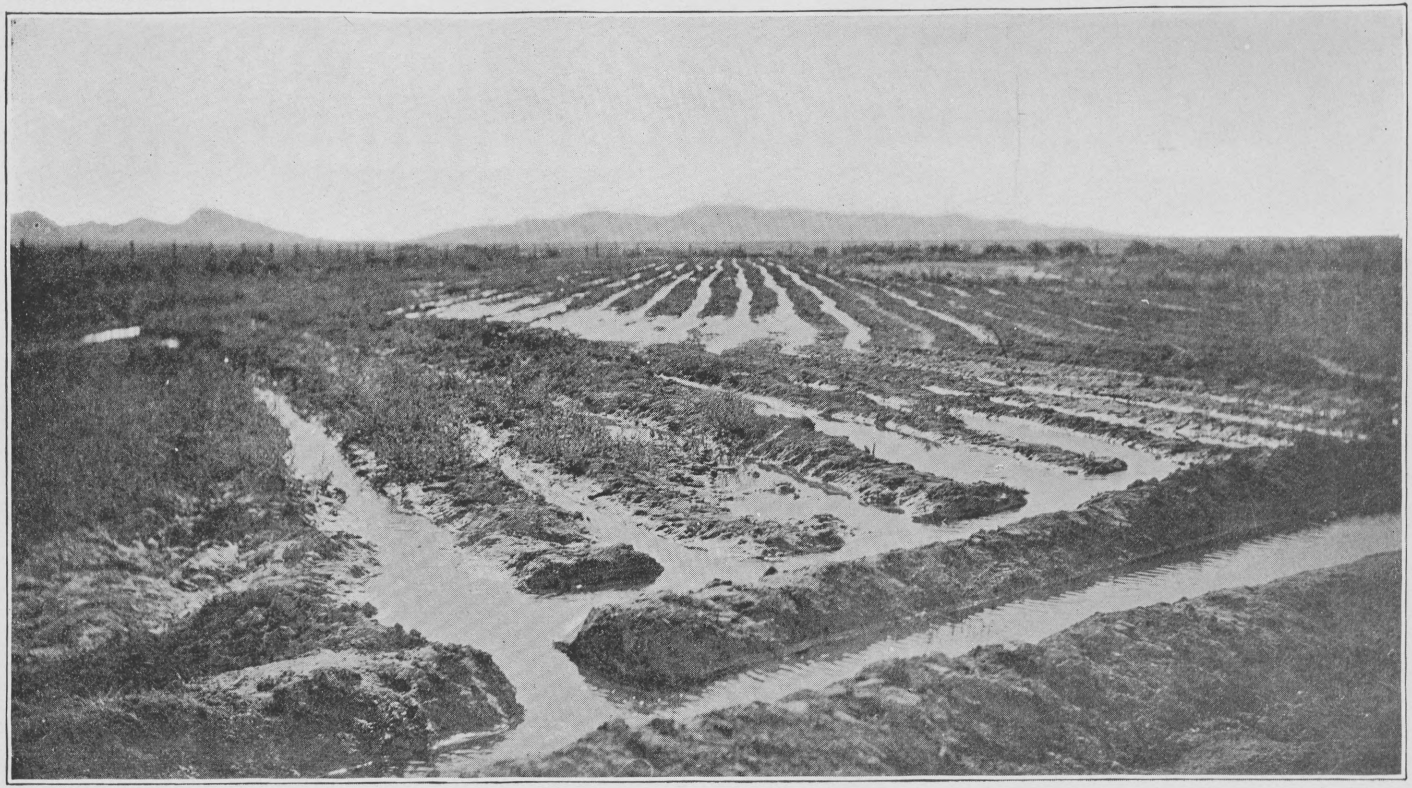
Following out to their sequence the propositions I have advanced as to the ownership of water and the right of appropriation, I am of the opinion that the entire right of the appropriator for irrigation is limited to the delivery of water sufficient for the purpose upon his land at a point where he can use it for irrigation, and that so long as such water is so delivered he may be indifferent to any acts of diversion or obstruction of the flow of water in the natural water course, and has no just cause for complaint therefor. He might be compelled to adopt a more expensive means of delivery of the water to his lands if the means that he has already adopted are such as would result in the loss of water; for, as we have repeatedly affirmed, the water is public property; it is a common stock to which all may go, and no man has any right by faulty construction of his conduits, or by their deficient construction, or by a desire to appropriate more than his share of the water, to diminish that common stock of the water to any greater extent than his necessities require.

This brings us to the question whether or not it is the duty of the prior appropriator to make use of such new means as may result in the more economical conveyance of water than those which he had heretofore provided for himself. Whether or not it would be his duty, if, for instance, he was an irrigator under the Tempe Canal, to construct a new conduit from the Highland Canal to his lands, and thereby conduct his water at a considerable saving of the common stock of water, assuming, of course, that the Highland Canal is capable of carrying, in addition to that which it is already under obligation to carry, the quantity sufficient for his use.

The variety of means adopted for the diversion of water vary under different conditions. The person who first appropriates usually finds in the natural water course a volume of water in excess of that which he himself needs, and to divert the comparatively small proportion of the whole volume which he may need would be inexpensive and easy of accomplishment. It is usually unnecessary for the first appropriator to construct a dam, or that he should excavate a ditch to the bottom of the water course whence he divert his water; because of the superabundance in the natural water course enough for his purpose may be diverted by less expensive means. As, however, others seek, subsequently, to appropriate a portion of the same stream above the point of diversion by the first, a diminution of the quantity of the water going down to the first appropriator results in such a reduction of the volume of water that the means adopted by the first appropriator will not enable him to continue his diversion, and he must, in order to get the water, either construct a dam so as to divert the water or excavate his ditch deeper, so as to reach and divert the water from the diminished quantity flowing in the natural water course. This would, of course, entail an additional expense upon the first appropriator.

To illustrate the question, let us suppose that upon a water course there is an average flow of water of 4 feet in depth; that the construction by the first appropriator of a ditch, the bottom of which is 2 feet below the surface of the water, enables him thereby to divert all the water he needs. Suppose that thereafter another appropriator constructs above the point of diversion by the first a ditch which appropriates 2 feet in depth of the water, and diminishes it so in volume that instead of flowing by the point of diversion by the first, 4 feet in depth, it now flows only 2 feet in depth. Still the quantity there flowing is sufficient to supply the needs of the first appropriator. It will be seen that the first appropriator can not, by the means then had, divert his amount of water, and there is necessarily entailed upon him an expense of either further excavation of the ditch or the erection of a dam in order to raise the surface of the water to a point at which it can be diverted into his ditch; and this additional expense is entailed by the act of the subsequent appropriator. It is not a question, as I have put it, of a deficiency in the supply of water, but it is merely a question of the right of a subsequent appropriator to diminish the volume of water flowing to such an extent that it can not be diverted by a prior appropriator by the means he then had. We think that it certainly can not be said that the first appropriator has the right to have the water flowing such a way that by his first means of diversion he can still continue his appropriation of the water. The whole policy of the law is, that all of the waters in the streams in this Territory should be used for mining, agricultural, and milling, and that there shall be no appropriation by anyone in a manner that shall prohibit subsequent appropriation by others, unless that subsequent appropriation leaves an insufficient quantity of water.

The court held that the title to irrigating water inheres in the land irrigated and not in the company diverting the water, and that priority of time at which the water was applied to beneficial use constitutes priority of right to use of said water, and that this priority was determined, not by the date of diversion from the river, but by the date of such actual beneficial use. Evidence was therefore taken to establish the date of actual irrigation of each tract of land under each canal, the date of such irrigation determining the beginning of the right to the quantity of water requisite for such irrigation. Each canal, therefore, was entitled in any given year only to such quantity of water as was necessary to irrigate the lands actually under cultivation, subject to similar rights of other lands previously acquired. The unit of area for this purpose was taken as 160 acres, or a quarter section, although fractions of such tracts were considered in rendering the decision, the lowest subdivision considered being 40 acres, or one-fourth of a quarter section. The duty of water was assumed as 64 miner's inches for a quarter section of land. A miner's inch was defined to be one-fortieth of a cubic foot per second, which made the duty of 1 cubic foot per second 100 acres. On this basis a decision



IRRIGATION SCENE.

was made, from which the following table was constructed, under the orders of the court:

Table showing for each year the number of quarter sections under each canal entitled to water from Salt River as per decree of court.

Year.	Salt River Valley Canal.	Maricopa Canal.	Tempe Canal.	San Francisco or Wormser Canal.	Utah Canal.	Mesa Canal.	Grand Canal.	Arizona Canal.	Total Number of quarter sections for each year.
1868	12½	1	-------	-------	-------	-------	-------	-------	13½
1869	22	6	-------	-------	-------	-------	-------	-------	28
1870	31½	14½	-------	-------	-------	-------	-------	-------	46
1871	48	24½	5	8	-------	-------	-------	-------	85½
1872	78½	28½	49	8	-------	-------	-------	-------	167
1873	90½	29	57	12	-------	-------	-------	-------	188½
1874	90½	31	57	12	-------	-------	-------	-------	190½
1875	90½	32	57	12	-------	-------	-------	-------	191½
1876	92½	36	57	12	-------	-------	-------	-------	197½
1877	95½	41	57	22	7	-------	-------	-------	222½
1878	102	53	67	22	24	23	2	-------	293
1879	104	65½	70	22	24	30	15	-------	330½
1880	109	84½	70	24	24	35	17½	-------	364
1881	116½	102	72	24	24	43	18½	-------	400
1882	117½	117½	90	27	26	50	23½	-------	451½
1883	118½	124½	90	28	38	59	43½	-------	501½
1884	119½	128½	95	28	38	62	45½	-------	516½
1885	120½	133	98	28	38	73	46½	43½	580½
1886	121½	135	105	29	38	75	47½	105¼	656¼
1887	122½	134	113	31	40	82	47½	192¾	765¾
1888	123½	139	117	31	55	82	48½	333¼	929¼
1889	123½	139	117	31	55	82	48½	350	946

The figures in the columns headed Salt River Valley Canal, Maricopa Canal, etc., indicate the number of quarter sections irrigated in the year designated in the column on the extreme left. Bearing in mind that priority in time denotes priority in right, it will be seen that although the oldest water rights are in the Salt River Valley and Maricopa canals, such priority extends only to the quantity of water necessary for those tracts which were irrigated previous to lands irrigated under other canals. Thus in 1873 the area irrigated under the Salt River Valley Canal was increased by 12 quarter sections over that of 1872, but the additional water necessary for this increase was secondary in right to all lands irrigated in 1872, whether under the Tempe, the Wormser, or the Maricopa Canal. It will be seen that 516½ quarter sections, or 82,640 acres, were irrigated in 1884, requiring under the adjudicated duty of water 826 second-feet. In addition to this, Hayden's mill was entitled to 1,100 inches, but this amount need not be deducted from the irrigating supply of the river, because the water from Hayden's mill returned to the river above the head of the oldest canals and could be rediverted by them for irrigation.

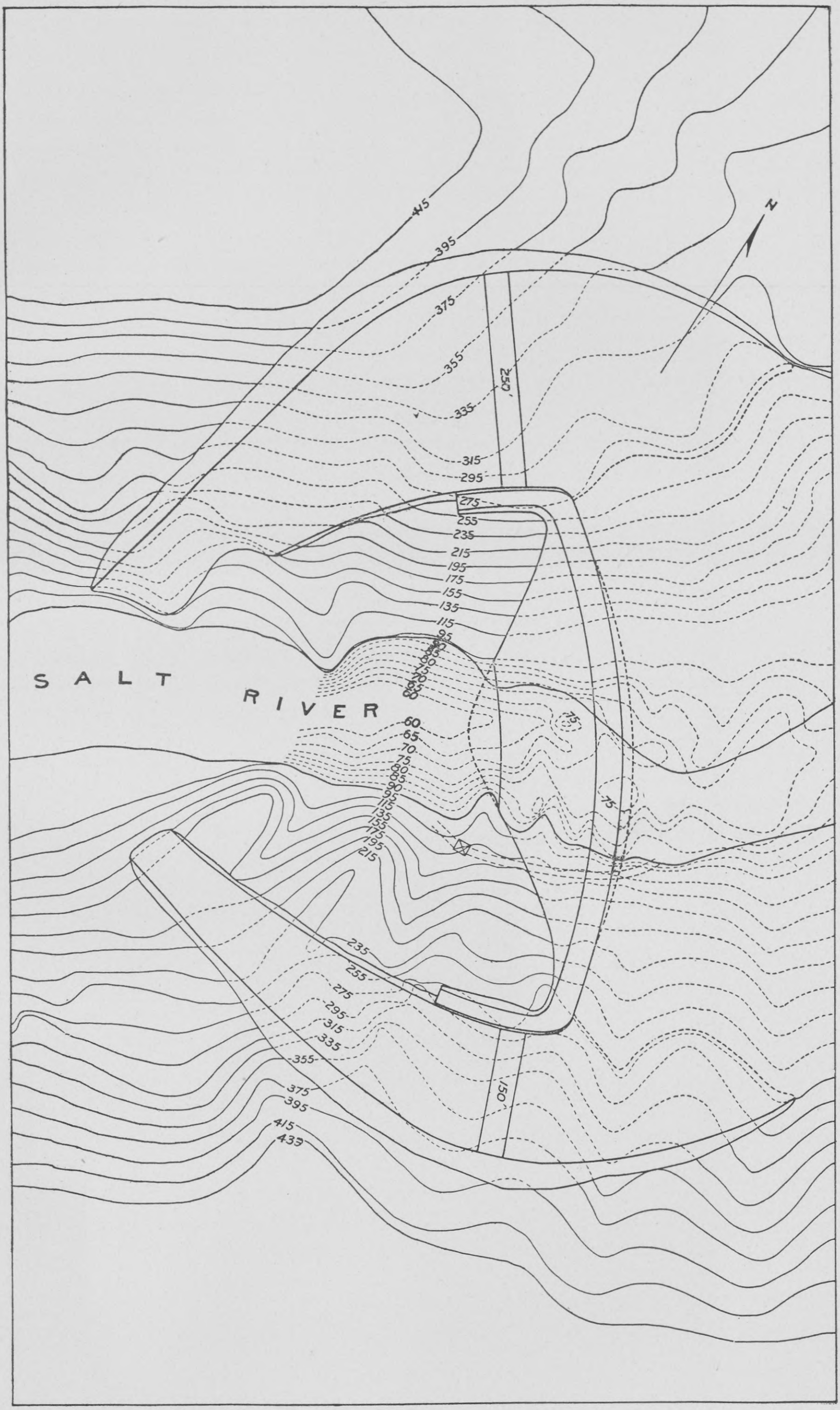
Considerable effort has been made by the later-constructed canals, particularly the Arizona and Mesa Consolidated, to establish claim to what is called the surplus waters or flood discharge of Salt River. These rights are of somewhat doubtful value for any purpose to which these canals can put them, for the high waters embraced by such claims are of short duration and can not be utilized to mature any crop. They are used for "soaking up" the ground during the period of high water in the hope that a portion of the moisture will be retained by the soil to mitigate the drought through the low-water season, when such waters can not be applied. It is obvious that such a use of waters is not a use at all, but a waste. It is not especially objectionable at present, except that in some instances farmers are thus encouraged to plant crops which can be matured only by the use of water obtained either illegally or through the generosity of some of the older proprietors. What standing such claims to the surplus waters can obtain in the courts remains to be seen. If they are sustained, the result will be disastrous to the future development of irrigation, for it is these surplus waters upon which any project for storage on the upper waters of the Verde and Salt rivers must largely depend. Such storage works will hold the surplus waters for use during the dry season, when they are most needed, but if title is held in the manner claimed, they will probably continue to be wasted as at present.

IRRIGATION WORKS PROJECTED.

Having noted the principal irrigating systems taking water from the Salt and Gila rivers, and reviewed in a general way the demands for water and the claims made upon the flow of these streams, it is pertinent to discuss at some length the attempts now being made to increase the available water by means of reservoirs and other works designed to save in part the waste water occurring in floods. The principal projects which have been surveyed by individuals and corporations or examined by the Government are known as the Rio Verde, Tonto Basin, Walnut Grove, Agua Fria, Cave Creek, Buttes, Lower Gila, and Queen Creek.

RIO VERDE.

This enterprise contemplates the storage of waters at the site on the Rio Verde known as the Horseshoe Reservoir, in T. 8 N., R. 6 E., Gila and Salt River meridian. The drainage area tributary to this reservoir is nearly 6,000 square miles. The proposed height of the dam at this point is 150 feet above the present surface of the river, and it will extend to a maximum depth of 25 feet to bed rock. It will be 386 feet long at the low-water line of the river, and 1,250 feet along the top. It is proposed to build this dam of a rock-filled type having side slopes of 2 : 3, made impervious on the water side by a sheet of asphalt pavement extending to bed rock. The spillway is situated over



PLAN OF PROPOSED DAM ON SALT RIVER, SHOWING SPILLWAYS.

2,000 feet west of the dam and is separated from it by a mass of rock rising over 75 feet above the spillway. It will be about 1,000 feet long. This reservoir will have a length of about 6 miles, a surface area of 3,402 acres, and a capacity of 204,935 acre-feet, as shown by the following table, which gives the area and capacity for each 10 feet elevation of the surface:

Area and capacity of Horseshoe Reservoir.

Contours.	Area, in acres.	Acre-feet between contours.	Total capacity in acre-feet.
10	39	270	270
20	99	690	960
30	268	1,835	2,795
40	442	3,550	6,345
50	720	5,810	12,155
60	974	8,470	20,625
70	1,178	10,760	31,385
80	1,398	12,880	44,265
90	1,665	15,315	59,580
100	1,916	17,905	77,185
110	2,109	20,125	97,610
120	2,349	22,290	119,900
130	2,646	24,975	144,875
140	2,982	28,140	173,015
150	3,402	31,920	204,935

Work upon the dam itself has not yet been begun, but the outlet tunnel is completed. It is intended to divert the river through this tunnel when necessary to complete the foundations. The tunnel is 715 feet long, 12 feet in diameter, with open-cut approaches.

About 18 miles below the Horseshoe Reservoir the water is to be diverted from the river by a dam 90 feet high and 475 feet long, of the rock-filled type. Here the canal is to head with a bottom width of 25 feet, depth of water 8 feet, side slopes 1 : 1, and a fall of 0.0003. The estimated mean velocity is to be 3 feet per second and the capacity 800 cubic feet per second. This section is continued for a distance of 54 miles, a considerable part of the distance being through rough country, with very heavy construction. At the end of the 54 miles the bottom width is reduced to 20 feet, and this width is maintained 15 miles farther to the crossing of New River. At New River it is proposed to construct another reservoir, partly to impound the storm waters of this stream, which is ordinarily dry, and partly to receive the waste waters from the canal. The proposed dam for this reservoir will be 100 feet high, with a top length of 1,800 feet, which it is said will impound over

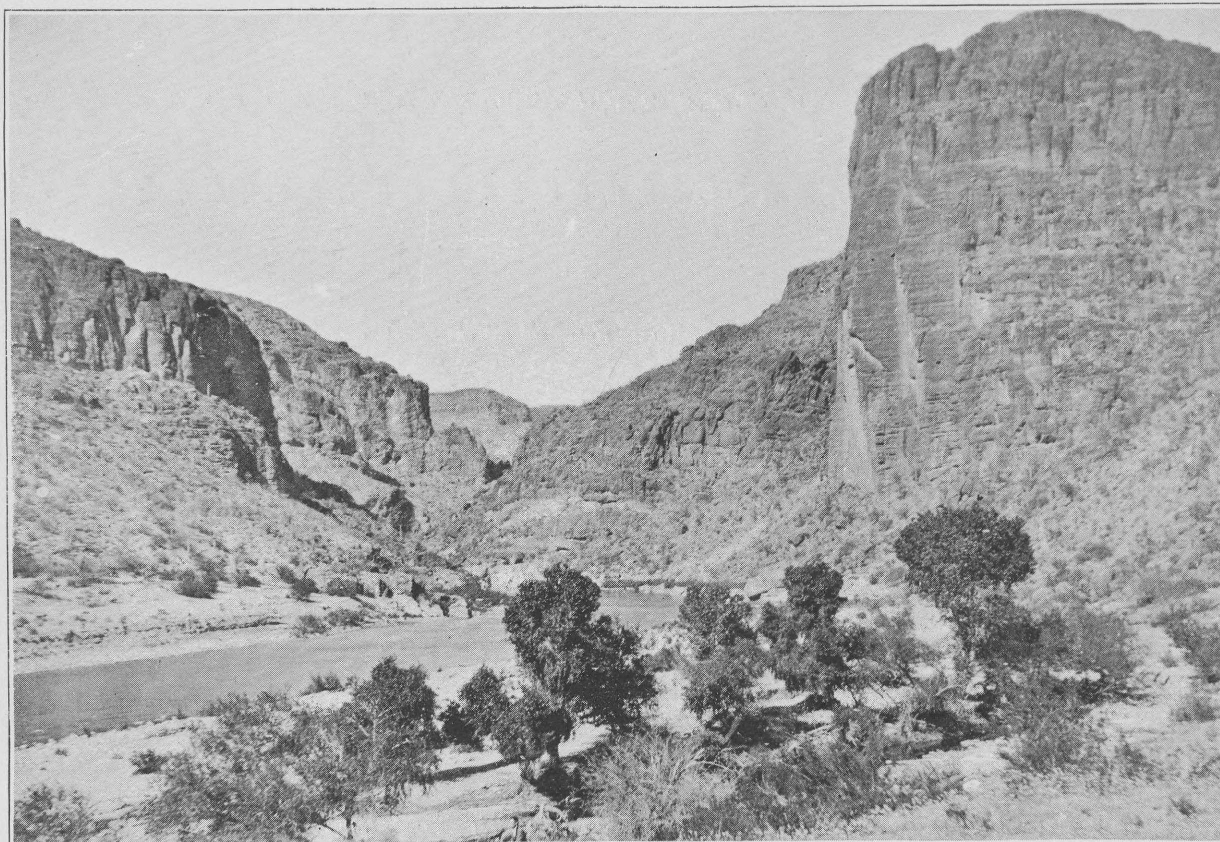
100,000 acre-feet of water. It is not intended to construct this reservoir at present, but it is contemplated as a future possibility after the development of the upper portion of the project. It is proposed to continue the canal from this reservoir on a grade line across the Agua Fria River, round the base of the White Tank Mountains, and across the Hassayampa, and to utilize another reservoir west of the Hassayampa, just above the Buckeye Canal, near the Four Buttes, which it is proposed to fill by a lateral feeder from the main canal. The land under this canal between Agua Fria and the Hassayampa rivers, as shown on the map, it is also proposed to irrigate from the Agua Fria Land and Water Company's works. The conflict of interests here, however, is more imaginary than real, as there is abundant good land to utilize all the water that can be furnished by both these projects and any others that may be constructed.

The estimated cost of the dam for the Horseshoe Reservoir is $600,000; the diversion dam is estimated to cost $200,000, and the canal to the Hassayampa is estimated to cost about $1,200,000, making $2,000,000 in all, exclusive of the two reservoir sites in the plains. It is estimated that from the head-gates to the Agua Fria River the canal covers an area of 125,000 acres of irrigable lands, including a very desirable tract of nearly 50,000 acres in Paradise Valley. West of the Agua Fria the land to be irrigated is an almost unbroken plain of sandy loam, and comprises more than 125,000 acres above the Buckeye Canal and east of the Hassayampa. As above stated, this project is under construction, the greater part of the work already done being upon the canal. The magnitude of the undertaking, the natural difficulties to be overcome, and the prevailing business depression combine to render its prosecution a matter of peculiar difficulty.

The company claims to have sold water rights for about 100,000 acres at prices varying from $10 to $18 per acre, paid for at the rate of $1 down and $1 per year thereafter. The payment of this $1 per acre each year is considered to be a sufficient compliance with the law requiring a person entering desert land to expend a certain amount in the use, irrigation, reclamation, and cultivation of the land. After the works are constructed the owners of the water right are to pay a certain amount per quantity of water used, the unit of measurement being the cubic foot. The rate charged is to be a gradually increasing one from $1.21 up to $2.42 per acre-foot after ten years. The maximum amount of water which can be demanded in any one year is at the rate of 2 acre-feet for each acre irrigated.

THE TONTO BASIN PROJECT.

Just below the junction of Tonto Creek with Salt River, near the line between Gila and Maricopa counties, Salt River passes through a deep, narrow gorge of solid rock. Above this point both streams flow through wide, level valleys, which are settled and cultivated to



VIEW IN CANYON OF SALT RIVER BELOW MOUTH OF TONTO CREEK.

a considerable extent. The Hudson Reservoir and Canal Company has made surveys and estimates, contemplating the construction of a dam at this point (fig. 9) about 215 feet high from bed rock and 610 feet long on top, which it is claimed will give a reservoir capacity of over 800,000 acre-feet. A spillway is to be cut around each end of

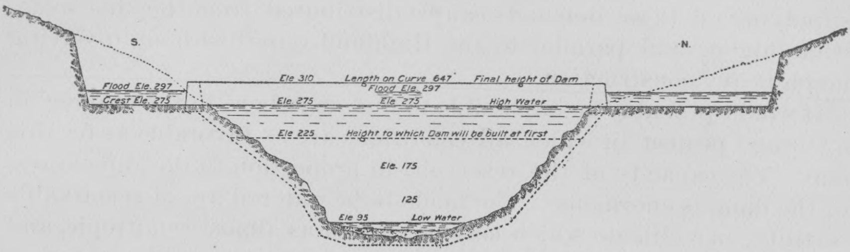


FIG. 9.—Elevation of proposed dam on Salt River.

this dam, as shown in Pl. XXI. It is proposed, first, to build a dam on an ogee section (fig. 10, *a*) about 140 feet in height, heavy enough to form the base of the dam of the full height, and to allow the flood water to pass over its crest after the reservoir fills. After the waters impounded by this reservoir have been disposed of the dam will be completed (fig. 10, *b*) and the additional waters will be sold.

Several lines have been surveyed for the location of a canal to con-

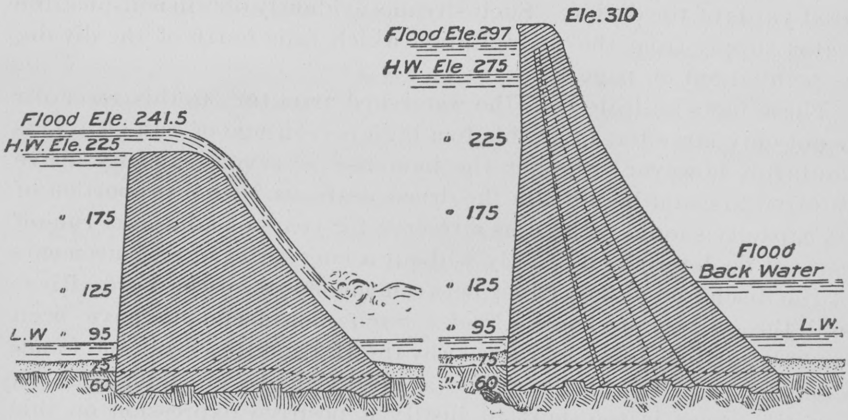


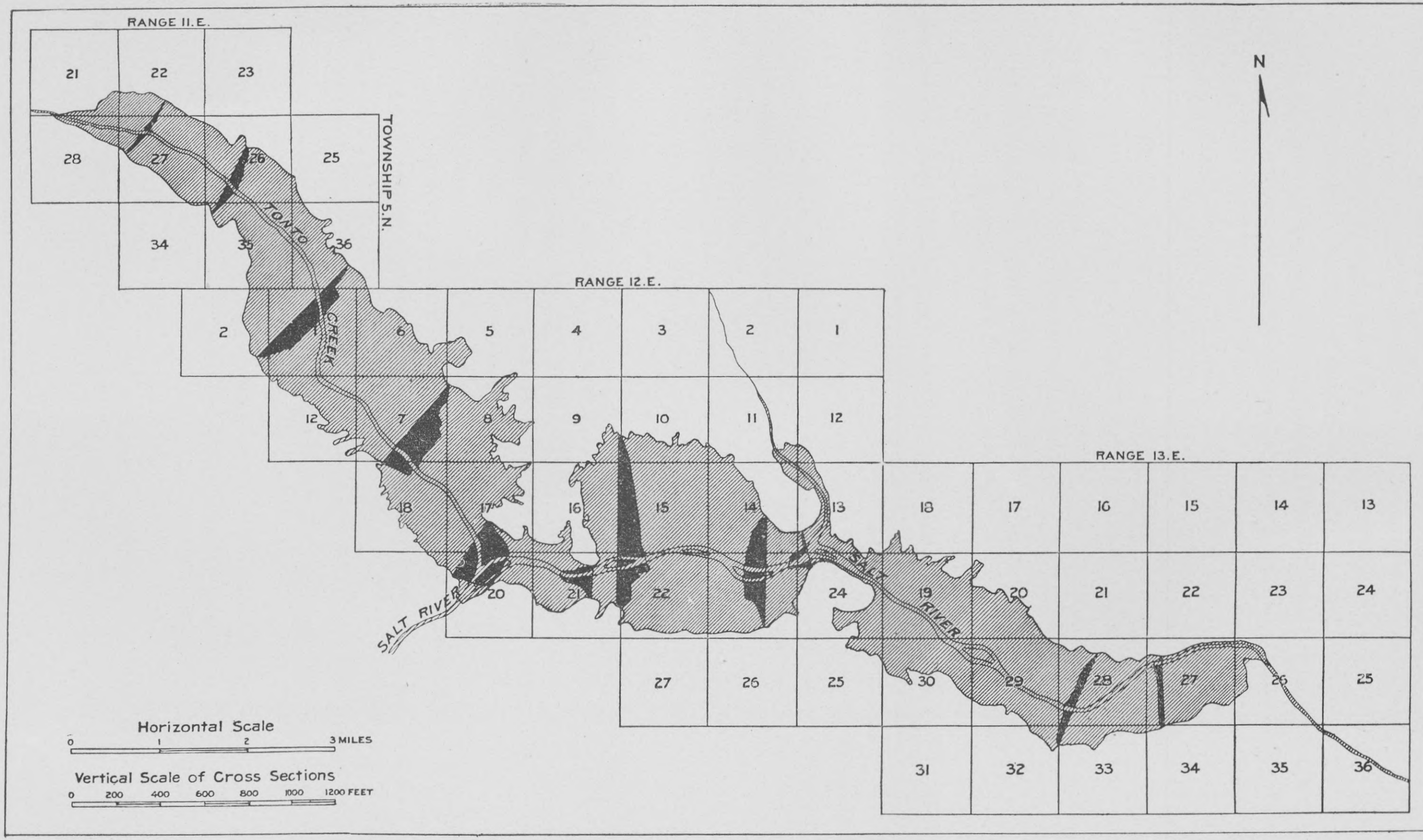
FIG. 10.—Profile of proposed dam on Salt River. *a*, first construction; *b*, completed.

duct these waters to irrigable lands on the south side of the river, and it has been shown that by diverting the waters well up in the canyon of Salt River they can be delivered high enough to water a large tract of land at present not under canal and to irrigate the greater portion of the valley lands on the Pima Indian Reservation. This involves a large amount of costly construction in the canyon, and it is not probable that such a line will be found advisable. Large tracts of uncultivated land are already under existing canals, particularly the Arizona, the Mesa Consolidated, and the Highland canals. Many of the older canals have also under them considerable tracts of uncultivated lands for which they hold no water right, and whatever waters are left after supplying all these demands can be distributed from the line somewhat higher and parallel to the Highland Canal without involving much heavy construction.

It would probably be impossible to find anywhere in the arid region a storage project in which all conditions are as favorable as for this one. The capacity of the reservoir, in proportion to the dimensions of the dam, is enormous. The lands to be watered are of remarkable fertility, in a climate which may be classed as almost semitropic, and are vastly greater in area than the water can supply. To a considerable extent they are already settled upon, and the water is in lively demand. The character of rock at the dam site is said to be excellent for the construction and foundation of the dam. There is tributary to this reservoir about 5,756 square miles of mountainous country, ranging in altitude from 2,000 to 12,000 feet, and including some of the best drainage area in Arizona. Many of the tributaries of Salt River find their source at the foot of the bold escarpment of the Mogollon mesa. Tonto Creek, for instance, heads at the foot of this mesa with the volume of a very considerable rivulet within a few hundred yards of the divide. Such streams evidently obtain considerable water supply from the precipitation which falls north of the divide, as pointed out on page 16.

These facts indicate that the watershed tributary to this reservoir is not only large but favorable to a high percentage of run-off. It is doubtful, however, whether the immense reservoir capacity above referred to could be filled in the driest years, and what proportion of its capacity should be held as a reserve for years of minimum run-off can not be determined exactly without a long series of measurements of the discharge of Salt River between the mouth of the Verde River and the mouth of Tonto Creek. Such measurements have been roughly carried on for over a year by the Hudson Reservoir and Canal Company, and the results, so far as observed, are given on page 39; but the series is too short to justify a positive expression on this point. There can be no doubt, however, that in this reservoir site lies one of the most important possibilities for the future of the agriculture of southern Arizona.

Pl. XXIII shows the outlines of this reservoir site as surveyed. The shaded portions represent cross sections on the lines indicated.



TONTO RESERVOIR SITE, SHOWING ELEVATIONS OF TEN CROSS-SECTIONS OF THE RESERVIOR.

Area and capacity of Tonto Reservoir.

Height above low water.	Capacity, in acre-feet.	Surface, in acres.	Elevation above sea level.
25	4,400	330	1,950
30	6,100	420	------------
35	9,000	570	------------
40	11,900	730	------------
45	16,200	890	------------
50	20,000	1,030	1,975
55	26,900	1,280	------------
60	33,300	1,510	------------
65	42,000	1,740	------------
70	50,700	1,980	------------
75	62,100	2,300	2,000
80	73,500	2,610	------------
85	88,500	3,010	------------
90	103,600	3,430	------------
95	122,700	3,820	------------
100	141,800	4,210	2,025
105	164,700	4,610	------------
110	187,700	4,990	------------
115	214,700	5,430	------------
120	241,800	5,860	------------
125	272,800	6,210	2,050
130	303,900	6,570	2,055
135	338,600	6,950	------------
140	373,400	7,350	------------
145	413,000	7,930	------------
150	453,000	8,530	2,075
155	498,000	9,110	------------
160	544,000	9,680	------------
165	594,000	10,170	------------
170	645,000	10,680	------------
175	701,000	11,240	2,100
180	757,000	11,750	2,105
185	820,000	12,300	------------
190	880,000	13,000	------------
195	950,000	13,600	------------
200	1,020,000	14,200	2,125

WALNUT GROVE RESERVOIR.

A storage reservoir was built on the Hassayampa River just below the settlement of Walnut Grove in 1888. The dam (fig. 11) was 420 feet long on top, 138 feet wide at bottom, 15 feet in width on top, and 110 feet high. As shown in Pl. XXIV, it was of the rock-filled or placer-mining type, consisting of a front and back wall of dry rock carefully laid with loose rock filling between. A wooden sheath covered the water slope to make it water-tight. This covering was fas-

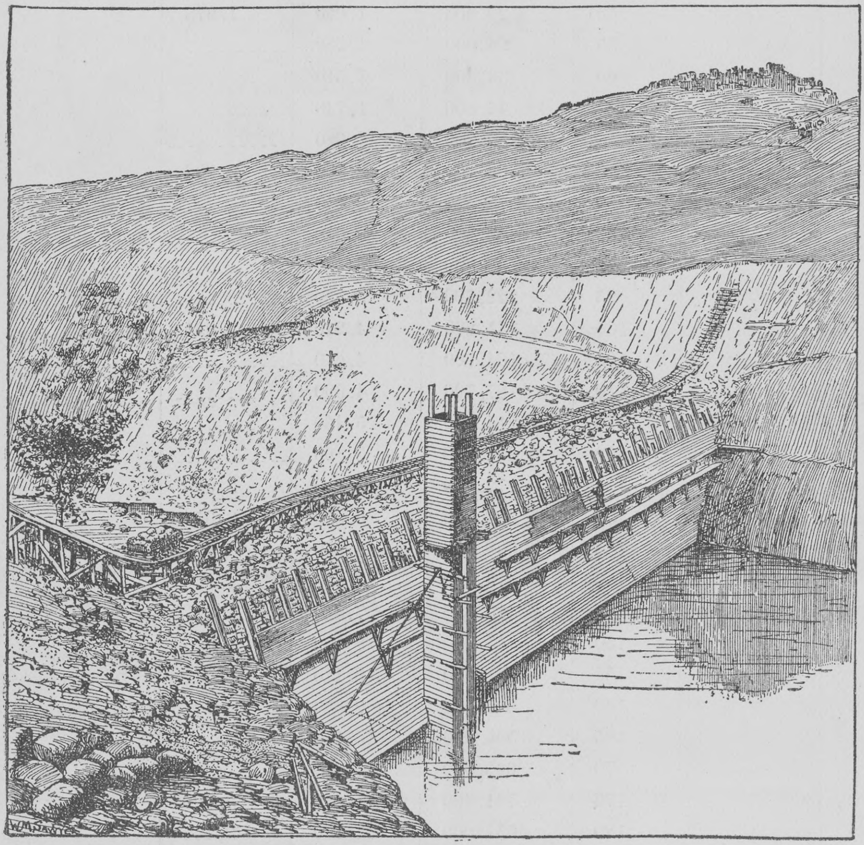
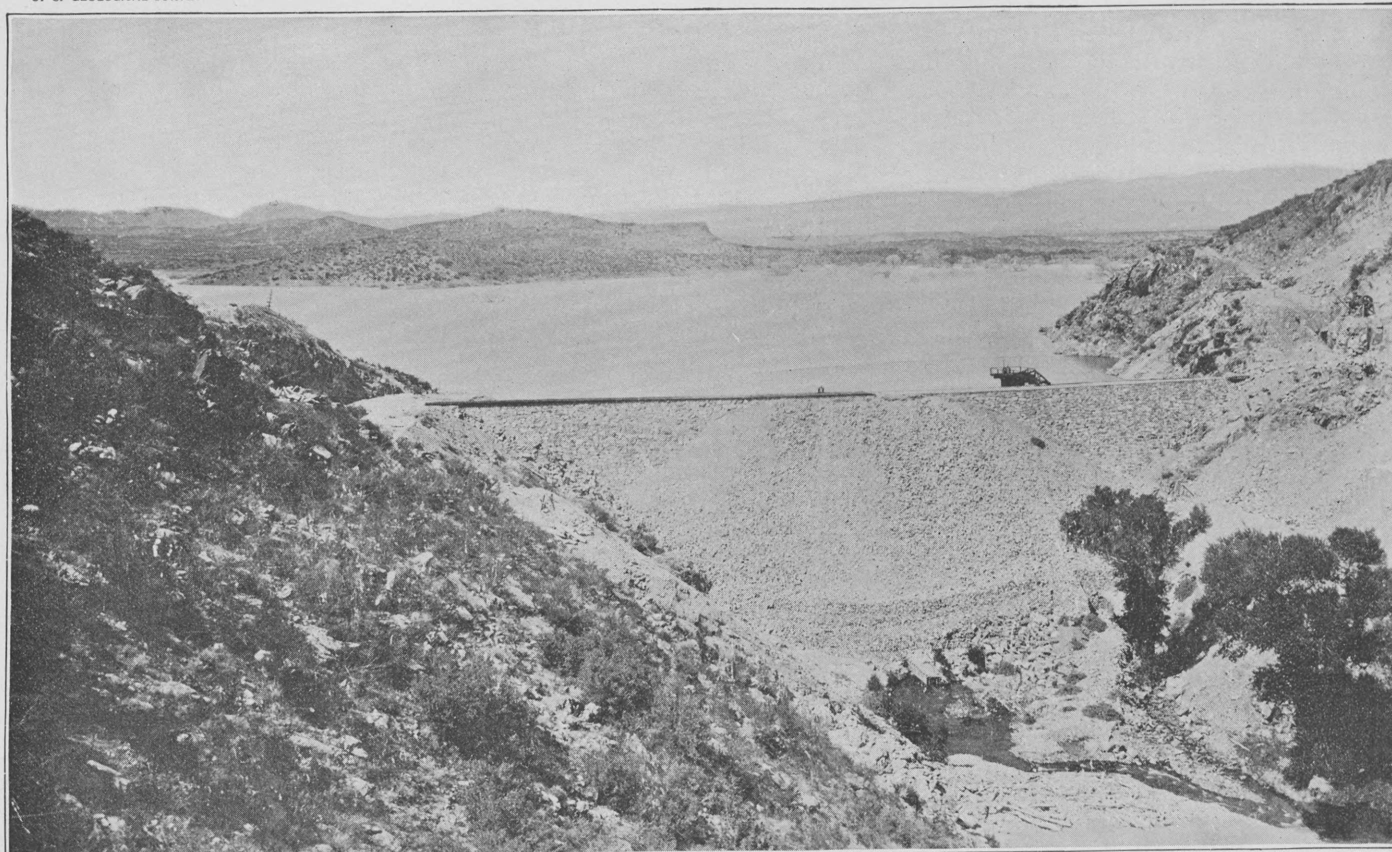


FIG. 11.—View of Walnut Grove dam.

tened to vertical stringers about 8 by 10 inches, which in turn were bolted to the projecting ends of heavy logs built into the upper face, the stringers being about 4 feet apart (fig. 12). The sheathing consisted of two thicknesses of 3-inch planking, with tarred paper laid between the two. The outer face was calked and covered with paraffin paint. Owing partly to the insufficiency of the spillway and partly to its becoming obstructed with driftwood, the great flood of



WALNUT GROVE DAM.

February, 1890, overtopped this dam, causing it to fail. The capacity of this reservoir has been variously estimated at from 7,000 to 14,000 acre-feet. Its destruction caused the loss of twenty-six lives and a considerable quantity of property in the valley below. A new reservoir could doubtless be constructed on the same site which would redeem at least 5,000 acres of the land.

AGUA FRIA PROJECT.

The Agua Fria Water and Land Company's project contemplates the construction of two reservoir dams and one diversion dam on

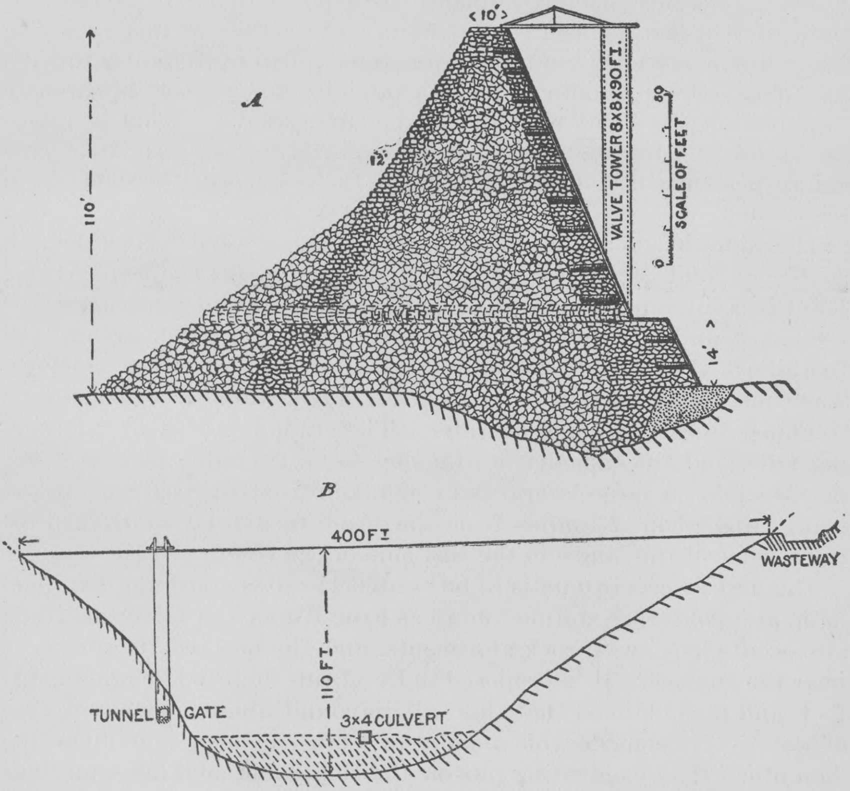


FIG. 12.—Cross section and elevation of Walnut Grove dam.

Agua Fria River. The diversion dam, a view of which is given in Pl. XXV, is already nearly completed. It is built of rubble masonry, laid in mortar made with a natural cement burned 25 miles southwest of the dam site, at the foot of the White Tank Mountains. The masonry cost about $4 per cubic yard, the stone being placed by cable conveyor, as shown in the plate. The total length when completed will be 650 feet, the greatest height above the creek bed 40 feet, in addition to which the deepest excavation to bed rock was 40 feet. The greatest width on bed rock is 53 feet. A spillway is to be provided around the west end. The upstream or back of the dam is vertical. The lower batter is 12½ in 20. Two sluices are left at the surface of the stream bed, each 4 feet wide by 6 feet high, to dispose of the flowing waters. The top width when completed will be about 8 feet. In October, 1895, a great flood came down the river, which the sluiceways were unable to discharge and which poured over the dam for several hours to a depth of more than 8 feet, finally carrying out a portion of the recently completed masonry, about 12 by 100 feet, near the west end of the dam. The portion remaining below that carried away exhibits a smoothly plastered surface with no evidence of fracture or indication of having been bonded in any way to the destroyed section. The rubble masonry contains numerous horizontal joints finished and plastered as smooth as though intended for a floor, apparently diminishing the bond with the next course above. This seems to be in direct contravention of good engineering practice, and to account in a measure for the failure of the portion of the dam above mentioned.

The canal heads at the east end of the dam in a cut 16 feet deep in solid rock, and is constructed for a distance of about 4 miles. At this point it is intended to carry the canal across the river in a flume 700 feet long, and to extend it in a southwesterly direction around the foothills of the White Tank Mountains toward the Hassayampa River. The constructed portion of the canal is 18 feet wide on bottom, and is intended to carry 8½ feet of water. The grade is 0.0004 or 2.11 feet per mile, and the capacity is intended to be 400 cubic feet of water per second. A large lateral is to be taken from the east side of the main canal about 2½ miles from the head, to extend southward for the service of the lands on the east side of the river.

The first reservoir dam is to be located 1¼ miles above the diversion dam, at an old stage station known as Frog Tanks. A fairly good dam site occurs here, with rock abutments, and the bed rock is said to be near the surface. It is proposed to build this dam to a height of 100 feet, and it is claimed that this will impound about 50,000 acre-feet of water. No considerable amount of work has been done upon this dam other than excavating pits on the slopes and making soundings to ascertain the depth to bed rock in the bed of the river. Quarries have been opened and a large amount of rock has been quarried and prepared for the work. The construction of this dam is to follow immediately after the completion of the diversion dam.

Eight miles above this place another dam site is located, in a gorge through solid rock, 262 feet wide at the bed of the river, and but 500 feet wide at a height of 200 feet. It is said that this basin will impound, with a dam 150 feet high, over 150,000 acre-feet of water.

DIVERTING DAM ON THE AGUA FRIA.

The plans of this irrigation project appear to be open to criticism, for by continuing the canal $1\frac{1}{4}$ miles farther up the canyon it would have reached the lower reservoir dam site, which is the next structure contemplated in the plans, and which would have served as a diversion dam, and the cost of the dam already constructed might thus have been saved. The construction of the canal through this distance would be expensive, as the country is rough, but it certainly would not approach in cost that of the diversion dam. Moreover, when in use the diversion dam will require to be filled to a height of nearly 40 feet above the bed of the creek to reach the intended height in the canal. This will form a pond of probably 40 or 50 acres constantly exposed to evaporation in this warm and arid climate. This loss is worth considering, for the water supply is the limiting feature of this enterprise, the capacities of the reservoirs and the land to be irrigated being relatively much greater than the water supply to be depended upon.

CAVE CREEK PROJECT.

The Pennsylvania Irrigation Company proposes to build a dam 100 feet high in the canyon of Cave Creek, which it is said will form a reservoir of more than 100,000 acre-feet capacity. The water is to be diverted about 7 miles below and used in the irrigation of the lands in Paradise Valley above the line of the Rio Verde Canal. As this drainage area is estimated to be only about 200 square miles, it seems improbable that this area will furnish sufficient water to justify the construction of a reservoir of this capacity; but a reservoir can doubtless be built at this point which will impound all the waters that can be depended upon from its drainage, and the land to be watered is abundant and excellent.

THE BUTTES RESERVOIR.

At a point about 14 miles east of Florence the Gila River passes between two buttes locally known as "The Buttes." For many years it has been proposed to build a dam at this point to store the flood waters of the Gila River for the reclamation of the arid plains below. This project was investigated by the writer in 1896 in connection with the water supply for the irrigation of the Pima Indian Reservation.[1] A detailed survey was made of the gorge through which the river passes, for the purpose of determining the best point for a dam and its dimensions and cubical contents. The scale adopted was 50 feet to an inch and the contour interval 2 feet, except where the slopes were too precipitous for this interval, when only 10-foot contours were drawn. After the completion of this survey the reservoir site to an elevation 200 feet above the bed of the river in the gorge was mapped

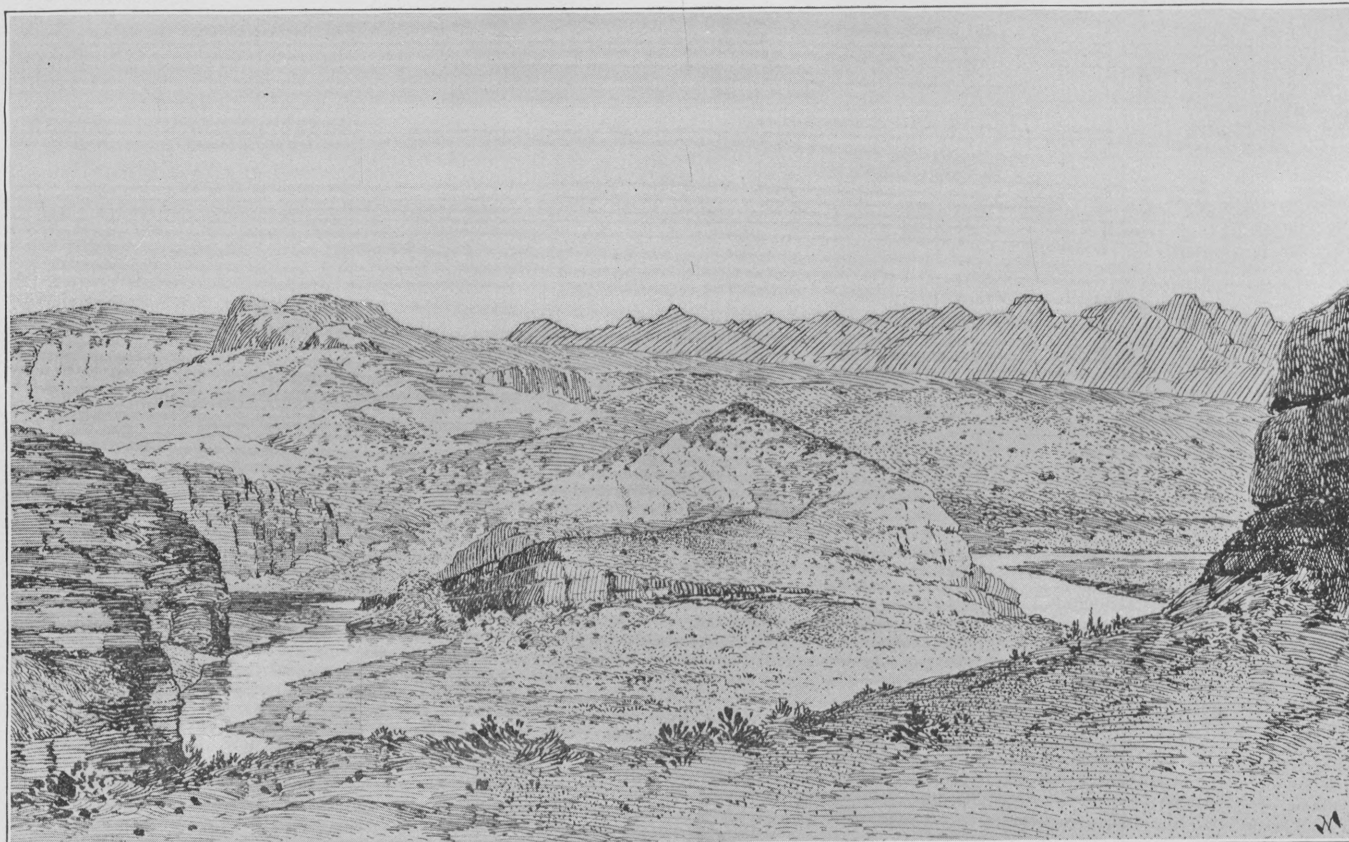
[1] Fifty-fourth Congress, second session, Senate Doc. No. 27.

on a scale of 5 inches to a mile in 10-foot contours. The reservoir capacities obtained by this survey are as follows:

Area and capacity of The Buttes Reservoir.

Contour flow line.	Area, in acres.	Capacity of section, in acre-feet.	Total capacity, in acre-feet.
10	20	100	100
20	71	450	550
30	229	1,500	2,050
40	397	3,130	5,180
50	533	4,650	9,830
60	741	6,370	16,200
70	928	8,345	24,545
80	1,105	10,165	34,710
90	1,329	12,170	46,880
100	1,566	14,475	61,355
110	1,769	16,675	78,030
120	2,029	18,990	97,020
130	2,367	21,980	119,000
140	2,746	25,565	144,565
150	3,149	29,475	174,040
160	3,602	33,755	207,795
170	4,118	38,600	246,395
180	4,609	43,635	290,030
190	5,133	48,710	338,740
200	5,651	53,920	392,660

Eleven soundings for bed rock were made at the dam site by driving iron rods into the gravel. What was supposed to be bed rock was reached at a maximum depth, near the center of the river, of 65 feet. The site proposed for this dam is where the river enters the gorge (Pl. XXVI), between the end of a projecting ridge on the east and a solid igneous dike on the west. It is proposed to build the dam to a height of 170 feet above the bed of the river, or 235 feet from bed rock. The top width is to be 12 feet; the upstream or back slope is to be 1 in 20, the face slope 1 in 2 from the top to a point 80 feet below the top, and 2 in 3 from that point to bed rock, as shown in fig. 13. A spillway capacity of over 100,000 cubic feet per second is to be provided, partly to the east and partly to the west of the dam. Both spillways will discharge their waters clear of the dam. This reservoir will have a capacity, as shown in the above table, of 205,000 acre-feet above the outlet tunnel, which will be about 30 feet above the bed of the stream. The outlet tunnel will pierce the hill to the southwest of the dam, and will be about 1,200 feet in length.



VIEW OF DAM SITE AT THE BUTTES, GILA RIVER, LOOKING NORTH.

Another and larger tunnel will be cut through the ridge to the east of the dam, on a considerably steeper grade, and discharge on a level with the river bed, for use as a sluiceway in clearing the reservoir of sediment. The discharge of the Gila River was measured by the United States Irrigation Survey for the year ending August 31, 1890.

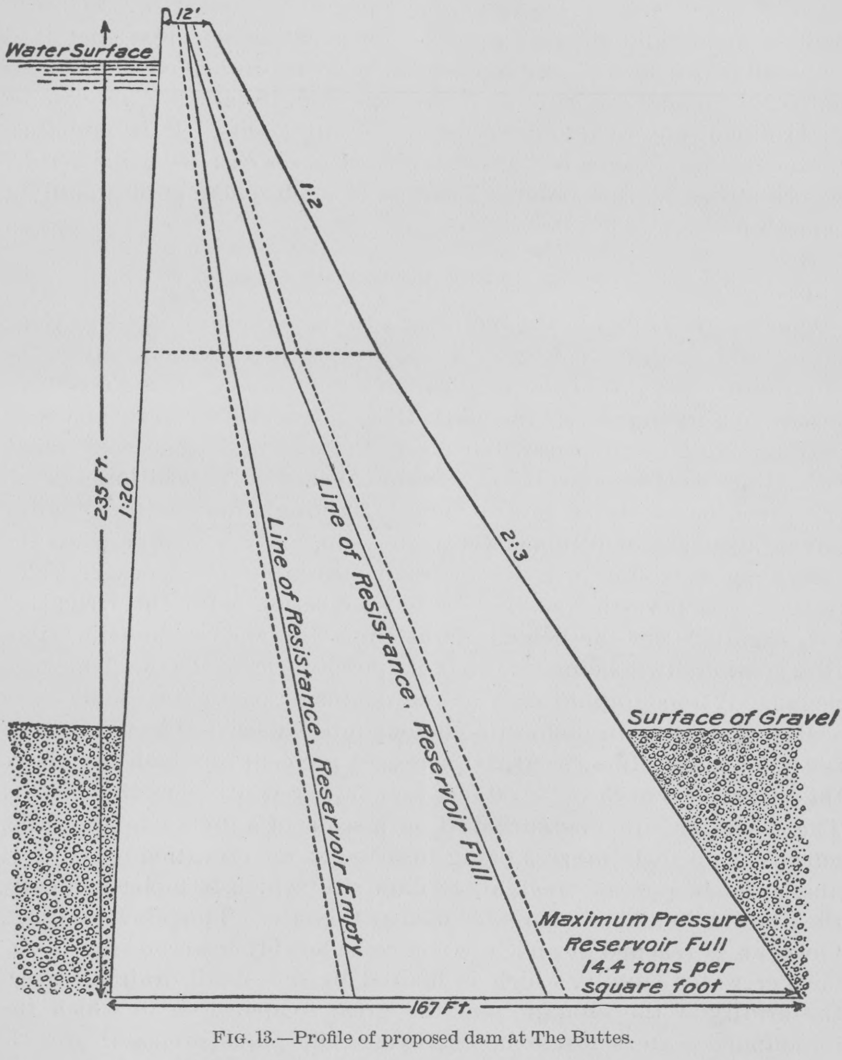


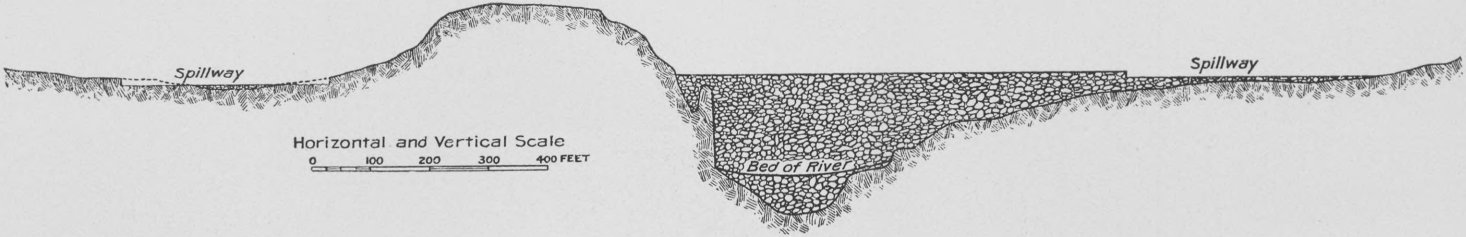
FIG. 13.—Profile of proposed dam at The Buttes.

The results of this measurement are given on page 40. Measurements for irrigation investigation, under the auspices of the Indian Bureau, were begun by the writer at the same point December 10, 1895, and continued until July 1, 1896, and they have been continued since that date to the present time by the United States Geological Survey. Previous to this private parties endeavoring to establish claim to this reservoir site took readings of gauge height and occasionally measured the velocity by the use of floats. With the data obtained in this manner, and by comparison with measurements made in 1896, the discharge of the river has been approximated from July to December. The results for 1895–96 are given on page 40, and a diagram of the discharge as actually measured is given in fig. 7. The area of this basin is so large, its topography so varied, the rainfall so small and erratic, and the evaporation so great that it is impossible to arrive at any conclusion from theoretical considerations as to the amount of run-off to be expected from it. This can be determined only by a long series of measurements. It is probable, however, that an area of 75,000 to 100,000 acres can be reclaimed by waters stored at this point. The cost of such reclamation would be something over $2,000,000.

QUEEN CREEK RESERVOIR SITE.

Queen Creek rises in the mountains to the eastward of Silver King mine, and, flowing in a general southwestern direction, leaves the mountains below Whitlow's ranch, and in ordinary years loses itself in the desert north of the Gila River Reservation. In times of extremely high and protracted floods the waters of this creek reach Gila River several miles below Sacaton Agency. At Whitlow's ranch the creek passes between two buttes, forming a narrow rocky gorge advantageously conditioned for a dam site, and above this point the valley spreads out in a broad basin favorable for storage. This project was investigated in 1896 in connection with the irrigation investigation[1] for the benefit of the Pima Indians on the Gila River Reservation, little being known of its possibilities when the field work began. A topographic map of the drainage basin was made on a scale of 1 mile to an inch, with contour intervals of 100 feet. Its area is 142.5 square miles, or 91,200 acres, 61 per cent of which lies above the elevation curve of 3,000 feet and 39 per cent below that curve. The reservoir site was surveyed on a scale of 5 inches to the mile, curves of 10 feet interval being inserted to an elevation of 140 feet above the bed of the creek at the dam site, which is topographically the limiting height of a possible dam at this site. The practical limit, however, is reached at an elevation considerably lower, owing to the meager water supply, which is limited by the small drainage area, the aridity of the climate, and the great evaporation to which the impounded waters would be exposed. The plans proposed provide for a dam 115 feet above the bed of the creek. It is to be built on the rock-filled plan, with a water slope of 1 in 1, a down-stream slope of 1 in 2, and a top width of 10 feet. (Fig. 14.) Upon the water slope is to be laid a sheathing of asphalt concrete, and from the upstream toe an impervious wall of cement rubble masonry is to be

[1] See report in Senate Document 27, Fifty-fourth Congress, second session.



ELEVATION OF PROPOSED DAM AT THE BUTTES.

carried down to bed rock, which, in the deepest place, is about 30 feet. An outer shell of carefully laid dry rock wall is to be built, which will be carried down to bed rock at the down-stream toe. Spillways will be excavated at each end of the dam, and it is from these that rock will be obtained for the construction of the dam. Little is known of the hydrographic possibilities of this basin, owing to the almost total absence of data on the subject. A record of rainfall ten months in duration was kept at Silver King, but its results appear to be of doubtful utility. Measurements of discharge were begun at Whit-

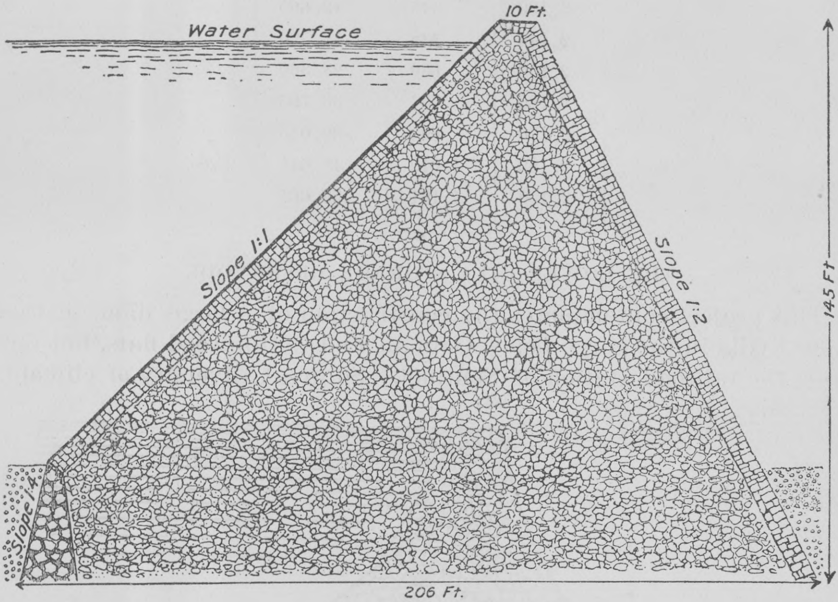


FIG. 14.—Profile of Queen Creek dam.

low's ranch in July, 1896. It is very difficult to make these measurements with any considerable degree of accuracy, owing to the extremely flashy character of the stream. Almost the entire discharge at this point is in the form of violent floods. It is estimated that a supply of about 10,000 acre-feet per annum can be depended upon from this project, sufficient to reclaim about 5,000 acres of land at a cost somewhere about $200,000. A table and diagrams of discharge of this stream may be found on page 42. An abundance of excellent land lies near at hand, with perfectly smooth surfaces and a maximum slope of about 40 feet to the mile.

Area and capacity of Queen Creek Reservoir.

Contour.	Area, in acres.	Capacity in acre-feet.
2,060	8	40
2,070	22	190
2,080	52	560
2,090	112	1,380
2,100	209	2,985
2,110	279	5,425
2,120	356	8,600
2,130	445	12,605
2,140	538	17,520
2,150	630	23,360
2,160	757	30,795
2,170	894	39,050
2,180	1,019	48,615
2,190	1,191	59,665

THE LOWER GILA STORAGE RESERVOIR.

This project contemplates the construction of a large dam on the Lower Gila in the gorge below Oatman and Cottonwood flats, not far from the railroad station of Sentinel. So great diversity of climate

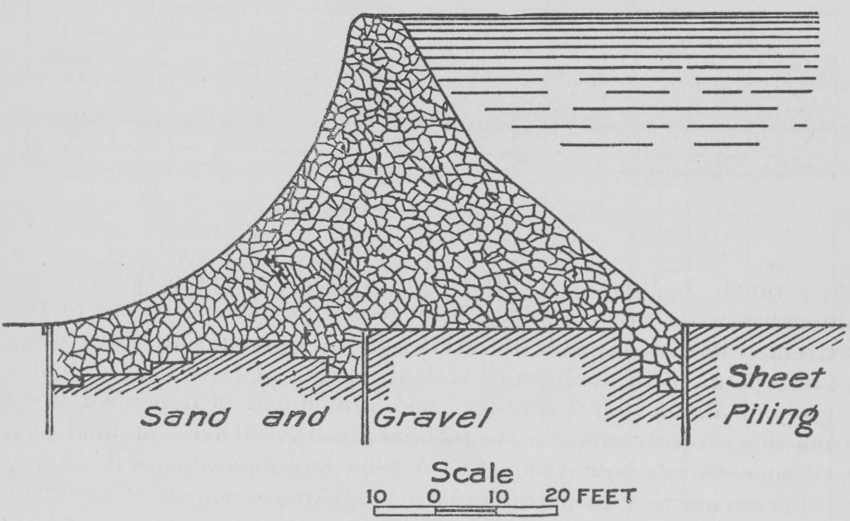
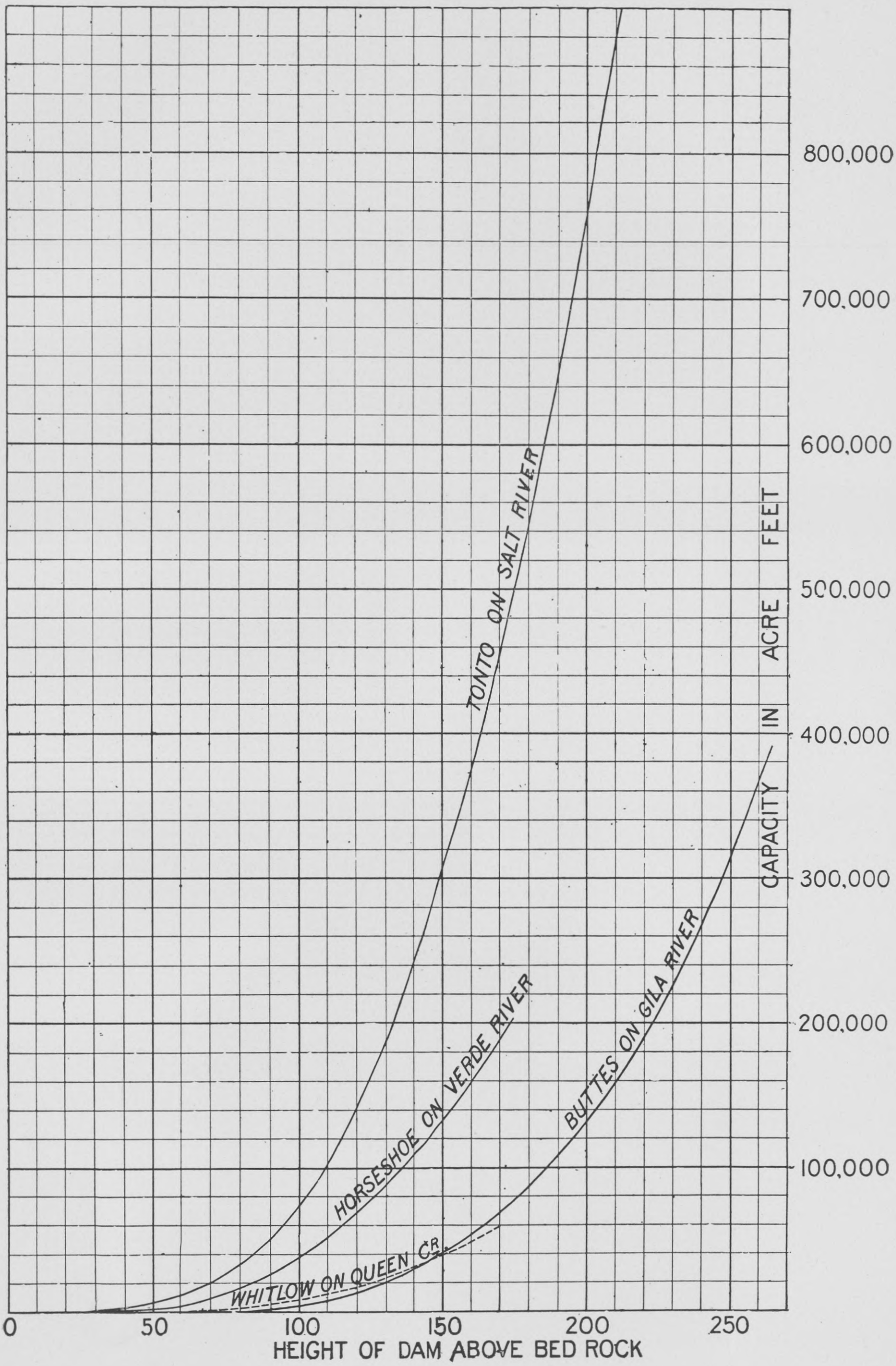


FIG. 15.—Section of proposed South Gila dam.

and topography is embraced by the drainage tributary to this reservoir that it is likely that it would receive a large run-off available for storage for irrigation and very materially increase the area reclaimable after all reservoirs in the upper portion of the basin are utilized.



COMPARATIVE DIAGRAM OF RESERVOIR SITES, GIVING CAPACITY OF EACH FOR VARIOUS HEIGHTS OF DAM.

Work on this reservoir was begun in 1892, but was discontinued, owing to financial difficulties, in the year 1893. It is the plan at present to construct at this point a dam 50 feet in height, a section of which is shown in Fig. 15. It is to be an overflow dam, protected on both faces with asphalt concrete. Seepage under the dam is to be cut off, so far as possible, by three rows of fluted sheet piling, one row at the toe, one at the axis, and one at the heel of the dam. This dam is to be utilized also as a diversion dam to raise the waters into the proposed canal, which will be taken out about 30 feet above the natural bed of the river, leaving 20 feet storage capacity above the bottom of the canal. The amount of this storage capacity is not known, but is undoubtedly great.

FUTURE DEVELOPMENTS.

Further development of irrigation in Arizona by the simple diversion of water from the Gila River and its tributaries is impossible. As already indicated, the dry-weather flow of these streams is overappropriated. The area irrigated from such streams can be increased by more economical use of the water now claimed, but the actual water supply for irrigation can be increased only by storage and in some degree by the development of underground sources.

NATURAL ADVANTAGES.

The vast extent of land in southern Arizona of surpassing fertility, admirably situated for irrigation, and with a climate the aridity and warmth of which make it at once exceptionally healthy and marvelously productive, and depending for its development and reclamation solely upon the practicable water supply, renders the item of water supply of vital importance to the future history of the Commonwealth. It is impossible in the present state of knowledge regarding this question to make even an approximate computation of the extent to which this water supply can be increased. Enough is known, however, to give to a summary of the known possibilities considerable interest and some scientific value. Unquestionably the main reliance for the increase in water supply is the storage of storm and winter waters and those of the season of melting snows, to be held and allowed to flow upon the land only as needed, instead of flowing to the sea, or of being applied for a short time in excess only to evaporate.

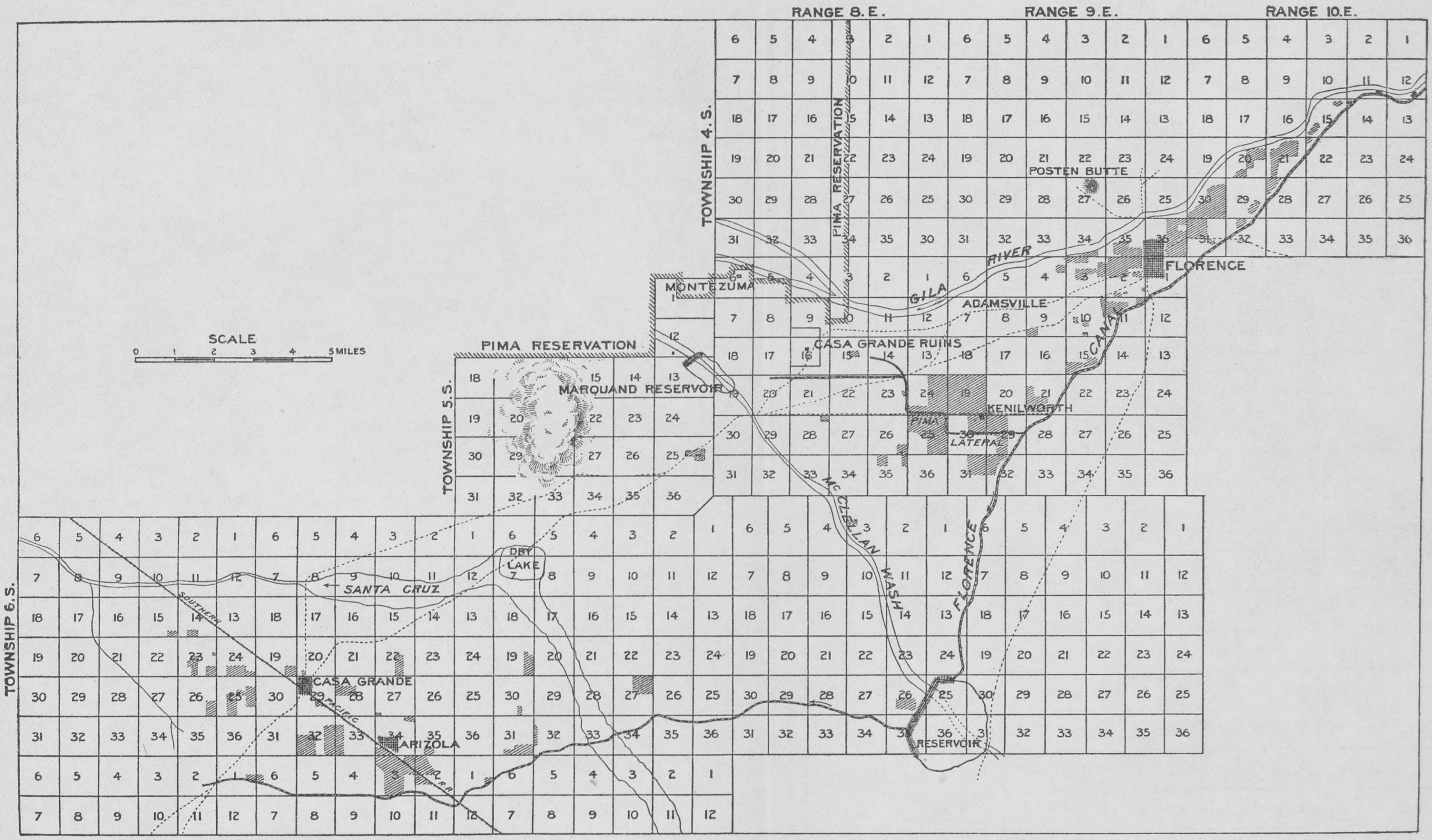
STORAGE OF FLOODS.

In some respects the topographic and climatic conditions in Arizona are peculiarly favorable for the complete utilization of its hydrographic possibilities. Few sections of the country are so well supplied with excellent reservoir sites favorably situated for the conservation of the surplus waters well above the areas to be irrigated. These favorable conditions seem to apply not only to the location and great capacity of the reservoir sites, but to their engineering practicability.

This is a point the importance of which is realized by few persons who have not made irrigation engineering a specialty. The impression seems to be well-nigh universal that wherever a locality is provided by nature with surplus waters that are discharged in torrents and wasted, such waters can be stored and entirely utilized for irrigation. As a matter of fact, the truth of this proposition is the exception rather than the rule. This is chiefly due to the scarcity of practicable topographic conditions for the construction of reservoirs at the place where needed. The storage of water for domestic use in cities is often accomplished where natural conditions are by no means favorable, because water for this purpose is far more valuable than it is ever likely to be in any part of the world for general irrigation purposes. While it may be practicable and economical in some cases for a city to pay tens or even hundreds of dollars per acre-foot for water for domestic use, any such price is absolutely prohibitory where the water is intended for irrigation on a large scale, even in those parts of the world where irrigation is brought to greatest perfection, where products are of the most exceptional nature and highest value, and water commands the maximum price. But even in the case of city supplies, it is by no means practicable in all cases to construct storage reservoirs at the required height within practical limits of expense.

It will thus be seen that for the storage of water for irrigation the existence of peculiar and favorable topographic and geologic conditions for the construction of reservoirs is of no less importance than the existence of waters to be stored. A basin of large capacity, capable of being closed by a structure of small dimensions and unquestionable safety, or if naturally already inclosed, capable of being pierced by a tunnel or cut for drawing off its waters, must exist at an elevation sufficiently low and in a locality convenient for the reception of the waters to be stored, and sufficiently elevated and convenient for its waters to be carried, within practicable limits of cost, upon the lands to be irrigated. Such reservoirs, furthermore, must be of considerable depth; otherwise the great bulk of the stored waters will be lost by evaporation before they can be utilized. This is peculiarly true of Arizona, on account of the excessive aridity and heat of its climate. Even with the most favorably conditioned storage sites this item of evaporation always curtails the efficiency of a reservoir site and places a limit upon its utility for the purposes intended. The less the value of the water impounded the more favorable must be those topographic conditions, but for any purposes of irrigation they must be so favorable as almost to be topographic curiosities, and such are of comparatively rare occurrence.

Another element of error in the popular assumption above referred to arises from the fact that the great floods which bear such immense



MAP OF FLORENCE CANAL, SHOWING IRRIGATED LANDS.

The shaded portions are the areas irrigated in 1896.

quantities of water running to waste and which make such a strong impression on the public mind are so infrequent in occurrence and so enormous in volume that their storage and complete utilization are impossible. The observation of these great floods, such as those of 1891, in both the Salt and the Gila rivers, produces an impression upon the popular mind that the possibilities of irrigation by storage are vastly larger than in fact they really are. Even assuming ideal conditions regarding the existence and location of feasible reservoir sites, we are forced by a study of the facts to the reluctant conclusion that such great floods bear no relation to the extension of irrigation by means of storage except to imperil the works. As before stated, these great floods occur only once or twice in a great many years, and irrigation can be extended only in approximate proportion to the supply of water that can be obtained in the driest years. To a certain extent dry years may be reenforced by the conservation of the waters from years of excessive run-off. Of course, the reservation of a large surplus over and above that required for irrigation in the year of great run-off requires the provision of extensive storage capacity and consequent increase in the cost of the works, but a limit to the utility of this method is quickly reached, especially in the climate of Arizona, by the heat and aridity there prevalent.

The potential evaporation is equivalent to a depth of nearly 8 feet in this region, and a reservoir in which the reserve storage filled it only to a depth of 8 feet would be entirely evaporated before the next season. If the reserve storage extended to a depth of 16 feet, it would be all lost before the second year was reached. To tide over a series of dry years a reservoir of great depth is necessary. When we consider the fact that all storage reservoirs which it is practicable to construct for purposes of irrigation have their greatest areas in the upper contours, it will be seen that to subtract 8, 16, 32, or 40 feet from the upper zones of such a reservoir is to lose an enormous proportion of its stored contents. For instance, in the areas and capacities of the reservoir surveyed at The Buttes, given on page 72, we find that for a depth of 150 feet the area of the reservoir is 3,149 acres and its capacity 174,000 acre-feet. Should it be attempted to hold such a reservoir filled with water for a period of say four years, we should have an evaporation of at least 30 feet from its surface, which would lower it to the 120-foot contour, at which the capacity is 97,000 acre-feet, or a little more than one-half the quantity which was held as a reserve. Should it be desired to hold a depth of 100 feet in the reservoir as a reserve for use in dry seasons, we find that in a period of four years, assuming the evaporation in that time to be 30 feet, the amount would be reduced from 61,355 acre-feet to 24,545 acre-feet, a loss of about 60 per cent. If the depth of reserve storage were adopted as 70 feet, we should have a capacity of 24,545 acre-feet, which would be reduced by four years' evaporation to about 5,000 acre-feet, or about 21 per cent, and another year would practically exhaust it. In the Sweetwater Reservoir, in southern California, 90 feet in depth, 80 per cent of the capacity of the reservoir is within the upper 30 feet of height and 40 per cent within the upper 10 feet.

It will be readily seen that the practical utility of a reserve storage is limited to three or four years, even with very deep reservoirs. With comparatively shallow reservoirs no such use is possible. Such great floods as occur only once or twice in ten or twenty years can not be held, even with unlimited storage capacity, to reenforce the years of minimum run-off, which of course occur at essentially similar intervals, and the meager observations at hand seem to indicate that they are not needed in the years in which they occur, as such years are likely to yield more than the average quantity of run-off, independent of such floods. On the other hand, they are a constant menace and a positive peril to the stability and perpetuity of the reservoir, owing both to their great magnitude and the great difficulty of determining what this magnitude is. Enormous and very expensive facilities must be provided for carrying them out of the reservoir without injury to the dam.

SILTING OF RESERVOIRS.

One of the most difficult problems presented in the storage of these great torrents is the enormous quantities of rocks, gravel, sand, mud, and silt which they carry into the reservoir, and even though no part of the flood may be held, the load of solid material is deposited and contributes to fill it and destroy its storage capacity. These terrible torrents, useless and dangerous as they are, contribute the major portion of the solid matter which is caught by such reservoirs, and this is one of the most serious and difficult problems to be solved by the irrigation engineers in southern Arizona. The amount of solid material brought down in this manner can be learned only by impounding and measuring it. Measurements of matter carried in suspension have been made on the Mississippi, on the Potomac, on the Rio Grande, and on streams in California, but even if these streams could be shown to bear any fixed relation to the torrents which it is proposed to control in Arizona the problem would still be unsolved, as an unknown quantity of such material is rolled along the bottom. This is proved by the large numbers of bowlders, small rocks, and gravel they carry which never could be held in suspension. Careful surveys have been made of new reservoirs in California with this problem in view, and after a lapse of several years a resurvey will doubtless furnish valuable information, but this is not available at the present time. The amount of solid material carried by the torrents of southern Arizona can be learned only by impounding it. As it is considerable, it is obvious that a reservoir built on such a water course will eventually fill with solid matter unless means are provided for its removal. No entirely efficient plan for this purpose has ever been put in operation.

It is usually assumed, and often with truth, that the life of the reservoir is sufficiently long to justify its construction, even though it will eventually fill and have its usefulness destroyed. The amount of material carried by streams in southern Arizona, especially in the summer floods, is too large and the necessity of the reservoir to the life of the district to be irrigated from it is too vital to justify this convenient solution, or rather evasion, of the problem.

At least one eminent engineering authority has expressed an opinion that such a reservoir, even when filled, would retain about 30 per cent of its available storage capacity in the voids of the material deposited. It would seem, however, that this opinion is entirely without foundation. The fluctuating character of such streams, as well as the widely variant specific gravity of the material carried, insures such a mixture of materials in regard to their fineness that the proportion of voids would be much smaller than in a body of sand or other material of approximate uniformity of size. By filling any given volume with coarse materials, such as bowlders, filling the voids of these bowlders with coarse gravel, these voids again with finer gravel, and so on through the coarser grades of sand to the very finest silt, using of each material just enough to fill the larger voids in the coarser material, a mass will be produced with an extremely small percentage of voids. This is roughly the course pursued in the manufacture of concrete, and apparently would be approximated by nature in the case of a mountain reservoir. But whatever the percentage of voids, the water contained therein would not only be held strongly by the forces of capillary attraction and surface tension, but the friction in the containing material would resist its escape so powerfully that even that portion which could be drawn off would escape with extreme slowness. While probably such a reservoir might store and yield for use a considerable quantity of water, it is clear that this quantity could not aggregate anything like 30 per cent of the original capacity of the reservoir.

It has been proposed to sluice out such material by providing large openings from the reservoir and occasionally allowing a large volume of water to rush out and carry the collected material with it. This method has been successfully employed in diverting dams for keeping open the approaches to the head gates of canals. It is also extensively employed in cleansing reservoirs in Spain. But experience has shown that only a comparatively small area is cleaned by this method, reaching on a steep grade for a moderate distance above the scouring sluices. For clearing a reservoir several miles long it is manifestly inadequate and must be supplemented by something else.

Another method of counteracting the tendency of the reservoir to fill is by enlarging its capacity. This method is not always possible. Where possible it is always expensive, and so far from being a solution of the problem, merely postpones the date when some means must be adopted of clearing out the impounded silt. It may, however, in some cases be advisable, where the expense is not too great, as the combined effect of raising the dam higher and of its filling with silt is to increase the altitude of the surface of the silt above the scouring sluices, and, by increasing the velocity of the water which is used in sluicing out the silt, to increase the efficiency of that means of cleansing the reservoir.

The removal of the accumulated débris by the ordinary methods of excavation is clearly out of the question. No community in the world can afford to pay for an acre-foot of storage capacity for the purposes of irrigation any sum approaching the cost of an acre-foot of excavation by the ordinary methods. A method is here suggested, however, which it is believed might be applied in many cases, and when properly adapted to the topography and hydrography of the locality, would, it is believed, be effective in some cases within practicable limits of expense. The method proposed is as follows:

A small water supply is to be obtained at considerable head over the reservoir site, either by diverting the stream at a distance above the reservoir or by storing waters in a small reservoir on the stream or some of its tributaries and carrying them in pipes or flumes above the upper edge of the reservoir to the vicinity of the dam. At points along the side of the reservoir which are topographically favorable, preferably upon ridges jutting out into the lake, hydraulic giants are to be provided, to act under the head of water furnished by the pipe line. Large sluiceways are to be provided near the dam, and at such times as the reservoir happens to be empty these sluiceways are to be opened to their full capacity and the deposited material hydraulicked out, as in hydraulic mining. The material, being mostly fine and freshly deposited, would wash easily and rapidly and be carried by the stream out of the reservoir through the sluice gates. This water need not be wasted, but could be diverted below for purposes of irrigation. It is not denied that such works and such methods would be expensive, but, on the other hand, their effectiveness is unquestionable, and it is believed to be by far the most feasible method yet proposed for cleaning out a large reservoir. The tendency of an economical use of this method would be to keep the reservoir open in its lower part, where it is deepest, and allow the shallow portions along the edges and at the upper end to remain filled. This would contract the relative area of water surface and diminish evaporation, which would in a measure compensate for the destruction of storage capacity.

The use of the three methods, first, the employment of one or more large scouring sluices, after the manner of the old Spanish reservoirs; second, the enlargement of the reservoir to the practicable limit; and, third, the construction of works and the adoption of operations like those above described, would in many cases insure the perpetuity of storage reservoirs in this country within practicable limits of expense. Certain it is that some efficient method or methods for this purpose must be employed or the extension of irrigation in any great degree in southern Arizona by means of storage is impossible.

The problem just discussed suggests the advisability, where feasible, of constructing storage reservoirs in side canyons or other basins having no considerable natural drainage tributary to them, the water being carried through artificial conduits from the streams whose waters it is desired to store. Where this can be done the danger of filling the reservoir with silt can be easily averted. Sand boxes can be constructed along a conduit and easily operated in such manner as to effectually clear the waters of their load of solid matter.

Aside from the scarcity of natural sites of this character, their efficiency is limited by a fact more strongly emphasized in this than in most countries, that the surplus waters are discharged in sudden floods of enormous volume, and in order to impound them or any considerable percentage of them by this method, not only must strong diversion works be provided for diverting them, but a conduit must be constructed of enormous capacity. If this conduit must be of considerable length or in very rough country—and both conditions usually obtain—the project is defeated by that great bugbear of irrigation possibilities previously referred to—the cost.

In respect to the existence of good natural reservoir sites upon streams carrying the bulk of its surplus waters, southern Arizona is particularly fortunate. The information upon this point, however, is far from complete, and the subject deserves careful expert investigation.

EVAPORATION.

As previously suggested, one of the most serious obstacles to the extension of irrigation in Arizona by means of storage is the high rate of evaporation, which often exceeds 100 inches in depth in a single year.

A compilation of evaporation results acquired by the Irrigation Survey is given in the Eleventh Annual Report of the Geological Survey, Part II, Irrigation, page 34.

It has been proposed to lessen evaporation from reservoirs by the cultivation of aquatic plants, whose leaves are intended to cover the surface and partially shade the water. This plan was suggested by Captain Glassford in Irrigation and Water Storage in the Arid Regions, page 307.[1] It is hardly probable that this method can be very effective, from the fact that such part of the leaves as are above water will probably transpire more or less moisture themselves, and such parts as are covered with a film of water of course can not check

[1] Fifty-first Congress, second session, Ex. Doc. No. 287, Irrigation and Water Storage in the Arid Regions, a report on the climatology of the arid regions of the United States with reference to irrigation. By Gen. A. W. Greely.

evaporation in any degree. A test of a similar method of checking evaporation was made by Prof. Edward M. Boggs, irrigation engineer and meteorologist of the Arizona Agricultural Experiment Station, the result of which is given by him in Bulletin No. 20, on Arizona Weather, page 7:

A second tank, an exact duplicate of the first, placed by its side, and provided with a similar gauge, was planted with water lilies of the genus *Nymphæ*. Measurements were commenced in this tank in September, 1892, when the leaves well covered the surface of the water. They were continued until April, 1894, when the gauge was needed for another use. A comparison of the results is shown by parallel columns in Table IV. It will be seen that the monthly totals of the two tanks are in substantial agreement. The differences are usually small. The excess changes so often from one tank to the other as to lead to the conclusion that differences are due to accumulations of errors incident to observation. But it is not easy to apply this explanation to the difference of 0.75 inch in favor of the lily tank occurring in June, 1893. However, the idea that the leaf covering has diminished the evaporation to any considerable extent is dispelled by the fact that for the eighteen months of the record the difference amounts to 1.52 inches only, a divergence of about 1 per cent.

Another device is here proposed which may be worthy of consideration, and which it is hoped may receive tests similar to those conducted by Professor Boggs. It is proposed to cover the surface of the reservoir with a film of crude petroleum, which will form a more or less coherent sheet of gum upon the surface and prevent the contact of air with the water as long as the surface of the reservoir is still and placid. The tendency of oil to diminish motion of water in waves and riffles is well known, and this project might prove more or less effective at such times as the winds are not too violent or constant. This suggestion is made for what it is worth, in the hope of inducing experiments to test its value. It must be admitted, however, that the prospect is meager for materially reducing the ravages of evaporation from reservoirs in this climate, and all plans and estimates should take them into account to the fullest extent.

MOUNTAIN RESERVOIRS.

It is eminently advisable in such a climate as that of Arizona to store waters for irrigation as far as practicable near their source, in order to obviate the enormous loss through evaporation when flowing for long distances through the sandy beds of streams.

It is often erroneously assumed that the run-off of a district is nearly proportioned to its area. In this arid region the mean discharge of the large streams is, owing to evaporation, often more nearly in inverse proportion to their catchment areas. Thus the Gila River at Yuma has a smaller discharge than at the mouth of Salt River, where its catchment area is far less. The Santa Cruz River, at the point where it leaves the mountains, discharges annually large quantities of water, which become progressively less, until well out into the desert the river is practically lost, and its discharge is zero. The same is true in a greater or less degree of nearly all the important drainage lines in the southern part of the entire arid region. Added to this is the fact that in the low, hot deserts the evaporation is usually so great as to make very serious ravages into the stored volume of water after the rains have ceased, thus materially reducing the supply available for irrigation.

The waters from a reservoir situated within a broad valley or open country must usually be conducted in broad channels constructed on light grades through sand or loam where the loss from seepage and evaporation will approximate a maximum; while from a mountain reservoir it is usually possible to give delivery canals heavy grades and high velocities, reducing seepage and evaporation to a minimum; and, with plenty of grade to spare, natural drainage lines may be utilized to a great extent. The seepage from high-level canals often reappears at lower levels and is not entirely lost. Furthermore, water stored in the mountains may usually be made to furnish a large amount of power that will in the future be very valuable, without in the least affecting its availability for irrigation. It may be laid down as an almost general rule that where there is a choice it is far better for the future of the arid region that water be stored in or near the mountains than on desert plains, even when the cost of such mountain storage is much greater than the same capacity at lower levels.

The reservoir sites already described on New River, Rio Verde, Gila and Salt rivers, Hassayampa, Queen, and Cave creeks, which are contemplated in the plans of existing companies, are doubtless the best that can be utilized on those streams, and are usually as great and in some cases greater in capacity than required for the economical conservation of the waters yielded by the drainage area tributary to them, exclusive of the great unusual floods which, as previously pointed out, it is neither practicable nor desirable to impound. On the drainage of the Gila proper, however, it is not improbable that undiscovered reservoirs exist in the mountains near the head waters of the Santa Cruz, San Pedro, San Francisco, and Gila rivers; Eagle, San Carlos, and Blue creeks, and other tributaries in the mountainous regions, where waters can be more economically stored than at The Buttes. When all such reservoirs are constructed and fully utilized, and the ordinary spring and summer flow of the river entirely diverted for irrigation in the neighborhood of Solomonville and Fort Thomas, the reservoir at The Buttes may be relied upon to impound the balance of the run-off tributary to its drainage, with the exception of the unusual floods referred to. This reservoir is admirably located for the purposes above outlined, being of large capacity and, situated at the point where the river finally leaves the mountainous region, intercepting nearly all the mountain drainage yielding the largest percentage of run-off, and yet of sufficient elevation to command all the irrigable land adjacent to the middle and lower portions of the river.

When all such sites are utilized there will still be a large area of excellent unwatered lands in the valleys of Arizona and a large amount of surplus flood waters, which, for reasons outlined on page 79, it is not practicable to store in the reservoirs in the mountains. Though these reservoirs include in their catchment the greater portion of the best drainage area of this basin, large areas of foothills, plains, and rocky ridges will still remain which are subject to occasional cloudbursts and yield in the aggregate a large run-off. A part of such waters, as well as such part of the seepage from canals and irrigated fields as finds its way back into the stream, can be impounded by the construction of a large reservoir on the lower Gila, as described on page 76. Whether it would be sufficient to utilize the water available for storage after the upper sites in this basin have been brought into use can not, of course, be known at present. Certain it is that no rights to flood waters should be acquired by such a reservoir to the prejudice of those in the mountain regions, where the water can be so much more economically impounded and applied, and in the absence of laws controlling this matter it is not to be regretted, but is rather a subject for congratulation, that this project has not been carried to completion; and it is to be hoped, for the sake of the future of irrigation in Arizona, that it will not again be revived until at least the best of the reservoir sites hereinbefore described have been constructed or some legal provision has been made to secure their full utilization.

UNDERGROUND WATERS.

The possibilities of irrigation by the development of percolating waters deserves mention. There is in Salt River Valley at present a large quantity of water in the gravels underlying the valley. The well employed to furnish the greater part of the domestic supply of water for the city of Phœnix is 35 feet in depth and 8 feet in diameter. It normally contains a depth of 18 feet of water. The walls are of cement, so that water can enter only at the bottom. Two Dean pumps, each of 840 gallons per minute capacity, are used to raise the water into the stand pipe. Both pumps usually run at nearly full capacity in July and August, and have raised 33,000,000 gallons per month. The discharge has sometimes exceeded 1,400 gallons per minute, which would lower the water in the well about 6 feet, but when the pumps are stopped the water recovers its level in a few minutes. A well was dug into the gravel in the vicinity of Mesa, and a centrifugal pump of about 1,200 gallons per minute capacity was used to keep the water down and permit the progress of the work. The ingress of water became so great as to be beyond the capacity of the pump, and work was stopped for that reason.

This large quantity of underground water is doubtless due to the excessive application of water, as previously described in this report, through the months of April and May, while the water in Salt River is abundant, and irrigators are attempting to "soak up" the land preparatory to the low-water season, when the competition for water rights becomes severe. If in future this excessive supply during the spring months is stored in great reservoirs, as is proposed by the projects now contemplated, the "underflow" will be greatly reduced, because so great an excess of water will no longer be applied to the fields. Some water will always escape from the fields into the subsoil, and canals and ditches will also lose a portion of their supply by seepage, which will be caught by the underflow. This source of supply, while for these reasons somewhat uncertain at present, is important in the future development of the valley.

Measurements were made in the month of June, 1896, by Mr. Cyrus C. Babb, of Salt River above the head of the Arizona Canal, of the amount of water taken out by each canal, and the amount remaining in the river below its head. These measurements proved that a considerable quantity of water is returned by seepage to the river bed, which was taken out for irrigation lower down. In one case the increase was 80 second-feet in 7 miles, as previously stated. Undoubtedly the amount lost by evaporation of these return waters from the river bed and the adjacent soils was much greater. While it is a gratification to know that some part of the surplus waters applied to the land returns to the river and can be used again, still this fact affords no excuse for such use, and should not be allowed to weigh in favor of its continuance.

In some other parts of the Territory are found underground waters in greater or less abundance, which may in some cases be profitably developed by pumping or otherwise for irrigation purposes. This is true at least in the country which receives the lost waters of the Santa Cruz and some other streams which have ordinarily little or no surface indications, but still discharge more or less water through a pervious subsoil. Water may be obtained in abundance a short distance beneath the surface along the valley of the Gila River, in the Pima Reservation.[1] Mr. Albert F. Colton has collected a quantity of data relating to wells in the Casa Grande Valley, some of which have quite a considerable flow and vary in depth from 20 to 100 feet. In other parts of the Territory wells have been sunk to depths greatly exceeding 100 feet without striking water. The information collected by the Geological Survey, together with that gathered by Mr. Colton, so

[1] Irrigation Investigation for Pima Reservation. Senate Doc. No. 27, Fifty-fourth Congress, second session.

far as relates to Maricopa and Pinal counties, is shown in the following tables:

Wells of Pinal County.

No.	Post-office.	Owner of well.	Location.			Year completed.	Diameter.	Depth of well.	Depth of water.	Cost of—	
			T.	R.	S.					Well.	Machinery.
							Ft. in.	Feet.	Feet.		
1	Arizola	Geo. W. Sanders	6	6	22	1892	4 0	40	3	$100	$13
2	do	Peter H. Loss	6	7	19	1893	4 0	44	6	35	
3	do	H. J. Cleveland	6	7	19		0 6				
4	do	Fred Weaver	6	7	32	1896	4 0	52	2		
5	do	—— Cooley	7	7	5	1895	4 0	53	3		
6	do	M. R. Mann	7	6	1	1894	3½ 0	54	2	54	
7	do	E. Hadley	6	6	34	1892	4 0	50	5		
8	Casa Grande	R. B. Dennis	6	6	20	1896	5 0	45	2		
9	do	Andrew Soundburg.	6	7	36		4 0	49	3		
10	do	L. S. English	6	5	23	1892	4 0	56	5		
11	do	F. G. Logan	6	6	32		0 6	75	30		
12	do	S. P. R. R	6	6	29		8 0	56	8		
13	Dudleyville	George Scott	4		25	1885	4½ 0	14	2	5	15
14	do	O. H. Swingle	6	16	20	1878	4 0	21	6	25	40
15	Florence	A. T. Colton	5	9	35	1888	4 0	45	1	56	
16	do	Whitney	5	9	10	1891	4 0	70	2		
17	do	Christopher Salmon.	5	7	25	1890	3 0	30	2	40	100
18	do	T. F. Marquand	5	7	13	1895	12 0	23	7½		
19	do	L. E. Graham	5	8	24	1891	6 0	56	6		150
20	do	J. M. Hurley	5	9	32	1891	4 0	102	31		
21	do	James F. Pry	5	8	27	1896	3 8	39.3	1.7	10	
22	do	Wm. H. Graham	5	8	28	1893	4 0	32	4		
23	do	F. E. Carpenter	5	8	35		4 0				
24	do	—— Morrell	5	8	26		3½ 0	44	4		
25	do	Daniel Bingham	5	8	26		4 0	51	2		
26	do	Shields & Price	5	8	24		3 0	66	5	66	300
27	do	Peter R. Brady	4		34	1884	4 0	27	2	90	
28	do	Abandoned	3	10	35		10 0	100	0		0
29	do	Thos. Buchanan	1	8		1885	0 5	232	24		
30	do	Whitlow Bros	2	10	1	1883	0 6	126	106	500	100
31	do	R. H. Martin	3	10	5	1883	0 6	413	0	1,600	
32	do	Harrington	2	7		1892	0 4	160	5		
33	do	Lew Baley	2	10	14	1888	0 6	180	0		
34	do	Mexican	1	10	34	1882	0 4	58	0		
35	do	Barmodath	1	10		1883	0 4	158	0		
36	do	Bark & Creswel	1	10		1879	0 6	18	9		
37	Kenilworth	W. J. L. Baron	5	8	25	1892	4 0	65	5½	65	
38	Maricopa	S. P. R. R	4	3	17	1885	16 0	34	5		
39	Sacaton	Wilson	6	5	24		4 0	42	2½		
40	do	W. J. Stulz	6	7	27	1895	3 0	52	3	50	
41	do	U. S. Indian agent	4	6			11 0	26½	8½		

Wells of Maricopa County.

No.	Post-office.	Owner of well.	Location.			Year completed.	Diameter.	Depth of well.	Depth of water.	Cost of—	
			T.	R.	S.					Well.	Machinery.
							Ft. in.	*Feet.*	*Feet.*		
42	Phoenix	E. F. Kellun	1	1	6		0 7	554		$5,000	
43	do	Frank A. Phillip	1	2	27	1892	14 0	26	14	300	$2,700
44	do	Phœnix Waterworks.	1	3	5	1889	8 0	35	17	5,000	10,000
45	Tempe	C. G. Jones	1	4	13	1889	4½ 0	20	12		
46	Mesa	Wm. Standage	1	5	20	1895	5 0	42	4	80	

No. 1.—Dug well; depth of water does not vary; it can not be easily lowered; flow has not diminished; water, soft; raised by bucket and used for domestic purposes; elevation of surface, 1,412. Strata passed through: Sandy soil, 11.5 feet; volcanic ash, 3 feet; hard whitish rock, 2 feet; sand and small gravel, 8.5 feet; wash gravel, 3 feet; hard whitish rock, 1 foot; gravel, 2 feet; hard rock of a water-line formation, 9.5 feet.

No. 2.—Dug well; depth of water does not vary, nor is it easily lowered; flow remained stationary; water rose 4 feet when struck; water, soft; raised by pump and used for domestic purposes; elevation of surface, 1,448 feet. Strata passed through: Clay soil, 6 feet; gravel, 8 feet; sand, 28 feet; rock of a water formation, 2 feet.

No. 3.—Bored well; elevation of surface, 1,452 feet.

No. 4.—Dug well; depth does not vary; is not easily lowered; quality of water, soft; raised by bucket and used for domestic purposes; elevation of surface, 1,458 feet. Strata passed through Clayish soil; last foot lime as water formation.

No. 5.—Dug well; depth does not vary during year; quality of water, soft; water raised by buckets and used for domestic purposes; elevation of surface, 1,460 feet. Strata passed through: Same as No. 4.

No. 6.—Dug well; depth does not vary during year; is not easily lowered; quality of water, soft; raised by bucket and used for domestic purposes; elevation of surface, 1,450 feet. Strata passed through: Clay, with streaks of gravel; bottom in sand.

No. 7.—Dug well; depth does not vary during year; is not easily lowered; quality of water, hard; water raised by buckets and used for domestic purposes; elevation of surface, 1,433 feet.

No. 8.—Dug well; water easily lowered; quality of water, soft; raised by buckets and used for domestic purposes; elevation of surface, 1,393 feet. Strata passed through: Clay soil, 12 feet; cement, 14 feet; sand, 12 feet; then clay to water.

No. 9.—Dug well; quality, soft; raised by bucket; used for house and stock; elevation of surface, 1,454 feet. Strata passed through: Sandy soil; bottom in sound rock.

No. 10.—Dug well; depth of water does not vary during year; is not easily lowered; flow has increased; quality of water, salt at first, hard now; raised by buckets and used for domestic purposes; elevation of surface, 1,375 feet. Strata passed through: Gravelly soil; water in gravel.

No. 11.—Bored well; depth of water does not vary during year; is not easily lowered; water, alkaline; raised by windmill; elevation of surface, 1,405 feet.

No. 12.—Water not easily lowered; it rose when struck; flow increased; water, hard; raised by pump; flow, 10,000 gallons per hour; elevation of surface, 1,395 feet. Strata at bottom: White sand.

No. 13.—Dug well; depth varies with height of river; can not be easily lowered; quality, a little alkaline; raised by pump; used for domestic purposes. Strata passed through: Alluvial soil, with sand at water level.

No. 14.—Dug well; depth does not vary during year; can not be easily lowered; water, hard; pumped and used for domestic purposes. Clay strata passed through.

No. 15.—Dug well; depth at first, 33 feet; water at 31 feet; sunk 1.5 feet each year; present depth, 45 feet, and 1 foot water; is easily lowered; flow diminished; elevation of surface, 1,488 feet. Sandy clay soil.

No: 16.—Dug well; depth varies during year; water, hard.

No. 17.—Dug well; depth does not vary; is not easily lowered; rose one-half foot when struck; quality, soft; used for house and stock; elevation of surface, 1,398 feet. Sandy soil; bottom in sand.

No. 18.—Dug well; depth does not vary during year; lowers about 3 feet and no more; raised by gang pump and horsepower; flow, 6,600 gallons per hour; used for irrigation; elevation of surface, 1,380 feet. Sandy soil for 13 feet; 2.5 feet clay; then water in sand.

No. 19.—Dug well; commences to lower in November and rise in April; variation about 1 foot; not easily lowered; quality, soft; raised by horsepower; waters 120 head of stock; elevation of surface, 1,455 feet; gravelly soil; bottom in water formation.

No. 20.—Dug well; depth does not vary; is not easily lowered; quality, medium; raised by pump; used for domestic purposes; elevation of surface, 1,505 feet; usual water formation of rock at bottom.

No. 21.—Dug well; quality, soft; raised by bucket; used for domestic purposes; elevation of surface, 1,440 feet; sandy soil on top water rock.

No. 22.—Dug well; water rises last of June, falls in December; not easily lowered; quality, soft, but getting hard; raised by pump; waters 20 head of hogs, 70 head of stock, 120 trees; elevation of surface, 1,416 feet; soil, sand and clay, with strata of hardpan at bottom, blue clay; main stream comes in from southeast.

No. 23.—Quality, soft; elevation of surface, 1,441 feet; same rock bottom.

No. 24.—Dug well; quality, salt; elevation of surface, 1,439 feet; sandy soil; bottom below water lime.

No. 25.—Dug well; quality, soft; elevation of surface, 1,450 feet; sand strata.

No. 26.—Dug well; depth varies during year; not easily lowered; quality, hard; raised by steam pump; elevation of surface, 1,467 feet; at 3 feet struck coarse gravel, lasting 20 feet; bottom in water lime.

No. 27.—Dug well; cased with redwood; lowers in summer; easily lowered; quality, soft and pure; soil, 11 feet alluvium, balance quicksand.

No. 29.—Dug well; size, 4 feet at top, 6 feet at bottom; level lowers some in summer; quality, soft; raised by steam pump, 1,000 gallons in twenty-four hours; used for stock, garden, and traveling public; strata, clay, sand, and small gravel, bottom in coarse gravel.

No. 30.—Drilled well; depth does not vary; can not be lowered with horsepower pump; used for stock; strata, limestone.

No. 32.—Dug well; depth lowers in summer; raised by horsepower and barrel; can be pumped dry in five hours; used for stock and by the public.

No. 33.—Drilled well; dry; 3 miles southwest of Whitlow's ranch; between this well and Florence are three other dry wells, with depths of 150 feet each.

No. 34.—Well sunk in Queen Creek wash, 2½ miles below Whitlow's ranch; no water found.

No. 36.—Well at Goldfield; more water in well in winter; can be easily lowered; raised by hand pump; used for stock.

No. 37.—Dug well; level rises in April, falls last of July; is easily lowered; flow has increased; quality, soft at first, now medium; raised by buckets, and waters 100 head of stock and 30 trees; elevation of surface, 1,465 feet; gravelly soil with streaks of limestone.

No. 38.—Dug well; not easily lowered; water soft; raised by steam pump; discharge, 10,000 gallons per hour; elevation of surface, 1,170 feet; gravelly soil.

No. 39.—Dug well; elevation of surface, 1,380 feet; bottom in gravel.

No. 40.—Dug well; depth does not vary during year; can be lowered by two buckets; water soft, raised by buckets, and used for domestic purposes; elevation of surface, 1,450 feet; sandy soil; water in a soft sandstone.

No. 41.—Dug well; capacity tested by 6-inch centrifugal pump giving one-tenth of a cubic foot per second, or 8,640 cubic feet per day; percolating area, 242 square feet, indicating a yield of 36 cubic feet per day for each square foot of surface. This surface is in a very hard clay, which has stood eight years without walling and still shows marks of the pick used in digging; water used for mill and domestic purposes; raised by steam pump.

No. 42.—Bored and drilled well; 18 feet to surface water; slight flow at 382 feet; not easily lowered; used for irrigation; alluvial soil 15 feet, hardpan 10 feet, alternate gravel beds 150 feet, sand, cement, etc.

No. 43.—Dug well; depth fluctuates about 30 inches during year; can not be easily lowered; quality, soft; raised by steam pump; discharge, 2 second-feet, and irrigates 320 acres.

No. 44.—Dug well; level not easily lowered; quality, hard; water raised by pumping; discharge, 2,500,000 gallons per day; supplies water to city of Phœnix; level steadily risen during past ten years; first 16 feet alluvial soil, balance bowlders and coarse gravel.

No. 45.—Dug well; cased for 6 feet; level varies 4 feet during year; can be easily lowered; quality, soft; raised with bucket, and used for domestic purposes; strata, soil for about 14 feet, hardpan of cement and rocks, gravel.

No. 46.—Dug well; walled with brick; depth varies during year; not easily lowered; quality, soft.

A scientific investigation of further possibilities is very important, both to develop resources along this line and to obviate further loss from unsuccessful attempts of this character. The irrigation possibilities from underground development are undoubtedly important, but it is not intended here to emphasize this fact, for the popular mind is already filled with very exaggerated ideas of such possibilities. Extravagant estimates of the quantity of "underflow" are rife on all hands, and it is recognized as an important though thankless duty to disabuse the public mind of such erroneous ideas so far as possible. One phase of this general impression is the opinion that the dry streams which abound in the valleys of Arizona must have a large underflow because the same streams carry considerable water farther up in the mountains. It seems to be forgotten that the potential evaporation in the valleys of Arizona ranges, according to locality and season, from 5 to 10 feet in depth on the entire area exposed to such evaporation.

It is the common assumption that evaporation is much higher from a water surface than from a saturated soil. The actual data on this point are very meager, but so far as observations have been taken they seem to indicate that evaporation is greater from saturated sands than from the surface of a deep body of water, even though such sands may appear dry on the surface. The reason for this may be found in the fact that the temperature of such sands rises much higher under the action of the sun than that of a large body of water; also, that for a considerable distance below the surface the particles of sand or of soil are kept moist by the action of surface tension and capillarity for a considerable distance above the point where all the voids in the sand are filled with water. By this means a far greater area of moist surface is exposed to the action of the dry air than is the case with a smooth sheet of water.

But whatever the reason, and whatever the exact ratio the evaporation from a sand bed bears to that of a body of water, we do know that it is very great, and that if the precipitation of the entire Territory of Arizona were so distributed as to give the potential evaporation of the climate full play, the evaporation would, even in the very wettest years, absorb the entire rainfall, and the run-off would at all times be absolutely zero. That the streams do yield a considerable quantity of run-off in the aggregate is due to the fact that precipitation is largely in excess of evaporation at certain times and in certain places, while at other times and in other places no moisture at all is exposed to the evaporating influence.

The above-recited facts are abundantly sufficient to account for the phenomena of many streams having a considerable discharge near their source in mountain regions and being ordinarily dry in valley regions, by the evaporation of the water from their sandy beds, without introducing the hypothesis of a large underflow. The Agua Fria is a typical stream in point. There are parts of its upper course in which it is ordinarily a very considerable stream and is never dry; near its mouth it is ordinarily entirely dry and carries water only in seasons of excessive rainfall. The idea seems to have been at one time prevalent that this stream carried a large amount of the so-called "underflow," but the construction of the dam of the Agua Fria Water and Land Company, a short distance below Frog Tanks, which was carried down 40 feet through the sands to bed rock, made little or no perceptible increase in the permanent volume of water flowing at that point. A measurement was made of the water flowing through the sluiceway of the dam in April, 1896, and this showed a discharge of only 3.75 cubic feet per second, which is said to have been about the ordinary flow previous to the construction of the dam. Another measurement made the same day about a mile above this point showed a discharge of about 3 cubic feet per second. The difference between these measurements may perhaps indicate the increase in the stream due to the development of the underflow, though even this is by no means certain. Even if the entire discharge of the stream were considered as developed from the underflow, its volume is nowhere near commensurate with the cost of development. While the experience in this case is of course not conclusive with respect to all other streams, it is an emphatic refutation of the popular theory that such water as falls in rain must be found either flowing in the surface streams or under ground. Attempts at extensive underground development should in all cases be preceded either by careful and judicious experiments or thorough scientific investigation.

The development of underground waters by means of pumps is greatly hampered by the scarcity and cost of suitable power. In some parts of the Territory firewood is at present abundant and cheap, but it is of slow growth, and if extensively employed in irrigation would in time become exhausted. The price of coal is prohibitory for any such purpose on a large scale in any part of the Territory, as is also that of petroleum, gasoline, or any other importable fuel. The time may come when some of the many available water powers in the foothills will be harnessed for the generation of electricity, to be transmitted to proper points and used for pumping water for irrigation, but these schemes can hardly be considered at present within the realm of practical consideration. A few attempts have been made to harness the winds to this work, but this motive power, always fickle and unreliable, seems to be especially so in these valleys; long periods of calm are said to occur during the months when water is most needed, and it is usually considered necessary to reenforce such plants with steam or other motive power. Some development, however, may be expected from nearly all the methods above mentioned, but for a long time to come they must necessarily be on a small scale and usually for individual purposes.

SUMMARY.

It may be in order here to point out some of the difficulties under which irrigation has heretofore labored, and to suggest means for obviating them in future. A glance at the map of Salt River Valley

DETAIL MAP OF SALT RIVER VALLEY, SHOWING THE VARIOUS CANALS CONSTRUCTED AND PROPOSED.

(Pl. XXX) will show at once that there has been an enormous waste of energy in the construction of numerous and parallel canals with conflicting claims and interests. On the north side of the river are the Farmers', Salt River, Maricopa, Grand, and Arizona canals, to be paralleled by the partly constructed Rio Verde Canal. All of the land under the Arizona Canal could be watered much more cheaply and with far greater economy of water from the Arizona Canal and its laterals. Most of the labor and capital expended in the construction of the others has been worse than wasted. So long as they are used in competition with a larger canal, acrimonious contests over water rights are the inevitable result, and when all concentrate under one management the competition for water rights is transferred from companies to individuals, and as long as the smaller canals remain in use they are a fruitful source of waste of valuable water. On the south side of the river the condition is, if possible, still worse. The Broadway and San Francisco ditches, and Tempe, Utah, Mesa, and Highland canals will be paralleled by a higher canal proposed by the Hudson Reservoir and Canal Company. They might be advantageously superseded by a single large, high-line canal, which would be far more economical of water, and all the labor and expense of the smaller canals would thereby be obviated. The greatest evil of the system, or rather lack of system, heretofore followed in the development of irrigation along Salt River, however, is the growth of conflicting claims to water. This has always been productive of vindictive and expensive litigation. Large areas of land have been brought under cultivation having no adequate water right, and crops have been dried up and labor wasted, and some areas abandoned, for lack of water for irrigation. This evil in this particular valley, so far as present conditions are concerned, may perhaps be largely remedied by the construction of storage works upon the Verde and Salt rivers; but unless means are employed to prevent it the same condition will again arise when the limit of irrigation is reached under the storage systems proposed.

Whatever claims are made to the contrary, it is a fact that the area of land to be irrigated in this portion of the Territory is much larger than can be served by any possible water supply that can be made available for such irrigation. Neither Arizona nor Salt River Valley is any exception in this regard to the rest of the arid region, but in Arizona and New Mexico the land and water are both still under the jurisdiction of the United States Government, and steps should at once be taken to determine where and to what extent the water resources can be most economically developed, and no irrigable land should pass out of the hands of the Government for irrigation purposes except such areas as it may be possible to irrigate. Persons should not be allowed to obtain possession of the lands to be irrigated except upon terms involving actual irrigation and cultivation. The absurdity and wastefulness of the contrary policy are strikingly illustrated by a study of the map of the irrigated areas under the Florence Canal. More than a hundred thousand acres of irrigable land might be conveniently served by this canal if it had a sufficient quantity of water. There are, in fact, about 6,500 acres watered from it, very little of which lies near the canal, and most of which is in small isolated tracts. To water such tracts in such a manner requires not only a large amount of construction upon laterals, which under any rational system would be unnecessary, but it also involves an enormous loss of water through evaporation and seepage from the long laterals required to conduct the water to the small scattered patches of cultivated ground. The water flowing through the Florence Canal during the year 1896 was more than treble that which would be required to mature the crops grown in that year had it been economically distributed and applied.

The following summary of the various conditions and possibilities regarding the irrigated areas of the Gila River and Salt River valleys must be taken with a large allowance for error both regarding existing conditions and future possibilities. It is, however, of some value and interest as representing in round numbers the results of the best data at present available to the public.

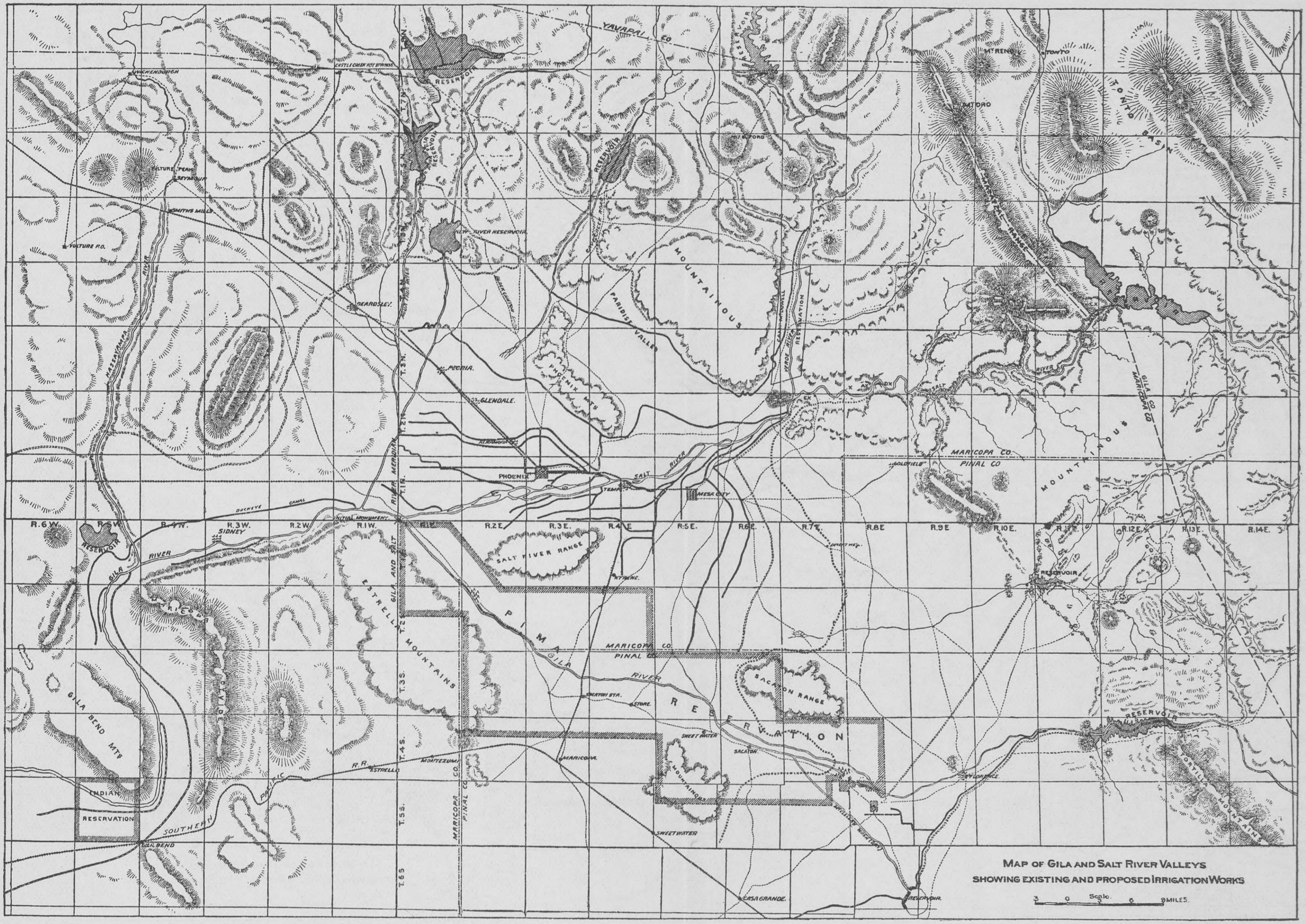
Summary of irrigation in Gila River and Salt River valleys.

	Acres.
Irrigated area in Cochise County	3,000
Irrigated area in Gila County	1,000
Irrigated area in Graham County	10,000
Irrigated area in Maricopa County	80,000
Irrigated area in Pima County	4,000
Irrigated area in Pinal County	7,000
Irrigated area in Yuma County	1,000
Total irrigated area	106,000

Additions may be made to the above area as follows:

	Acres.
Rio Verde Canal project, including New River Reservoir	150,000
Tonto Basin project	300,000
Agua Fria project, both reservoirs	80,000
Cave Creek project	10,000
Queen Creek project	5,000
Walnut Grove project	5,000
The Buttes Reservoir	100,000
Oatman Flat Reservoir	50,000
Various small reservoirs on tributaries of the Gila	50,000
Underground developments	20,000
Total	770,000
Already irrigated	106,000
Grand total	876,000

It is believed that these estimates are generous and that it will be very many years before the above figures are approached in actual practice. Of course other possibilities exist in Arizona from the use of the waters of the Colorado and its tributaries other than the Gila system. This estimate includes only the Gila system, and though the above figures are only rough estimates, they are suggestive of the importance to the future of Arizona of some comprehensive system of irrigation administration based upon principles of broad economy, and especially of the necessity of an exhaustive investigation of the water resources and of the most efficient means of utilizing them.



MAP OF SOUTHERN ARIZONA.

INDEX.

o